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TEST AND EVALUATION OF GRAPHITE/EPOXY COMPOSITE STRUCTURE.(U)

JUL 79 R P HEWITT, F H KOO, R D KEYS DAAG46-79-C-0006

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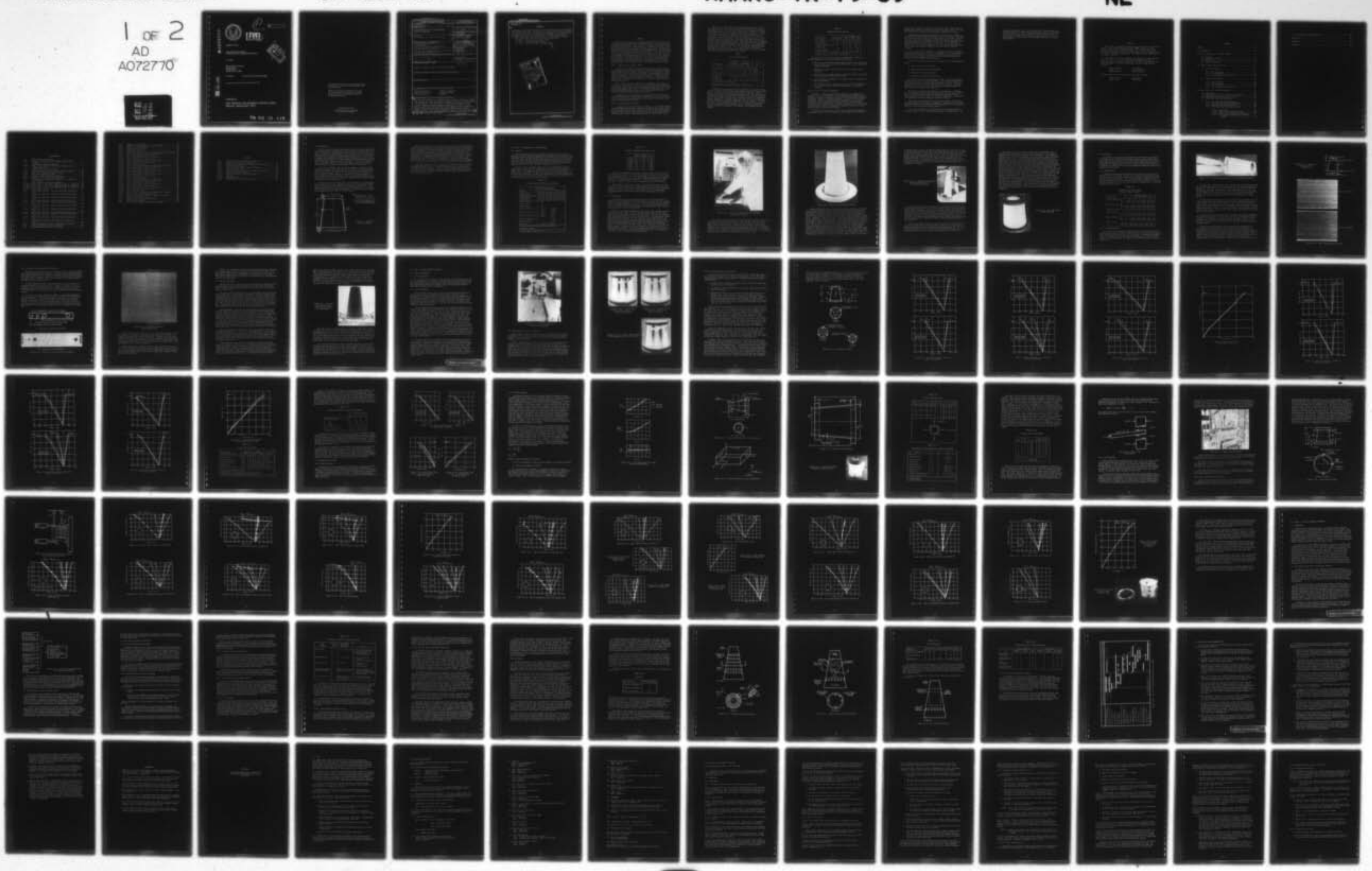

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LEVEL II

AMMRC TR 79-39

TEST AND EVALUATION OF GRAPHITE/EPOXY COMPOSITE STRUCTURE

July 1979

Martin Marietta Corporation
Orlando Division
P.O. Box 5837
Orlando, Florida 32855

Final Report Contract Number DAAG46-79-C-0006

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Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
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The test and evaluation of a graphite/epoxy structure is part of a technology program to develop and validate composite structures for BMD interceptor applications. This contract is essentially an extension of work recently completed by Martin Marietta Corporation on Phase I of the Advanced Structures Prototype (ASP) program conducted for the Ballistic Missile Defense Advanced Technology Center (BMDATC) under Contract DASG60-77-C-0111. This report presents the results of the test and

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ABSTRACT

evaluation of six subscale conical frusta during the period from November 1979 through March 1979. The objective of this evaluation was to provide an increased structural data base for the assessment of the strength and stiffness properties of ultra-high modulus GY70/934 graphite/epoxy structure fabricated by the hand-laid gore, autoclave cure processes.

The contractual effort was divided into three tasks:

- Task 1 - Fabrication of Conical Frusta;
- Task 2 - Static Testing of Frusta;
- Task 3 - Plan for Further Development.

SUMMARY

The test and evaluation of a graphite/epoxy structure is part of a technology program to develop and validate composite structures for BMD interceptor applications. This contract is essentially an extension of work recently completed by Martin Marietta Corporation on Phase I of the Advanced Structures Prototype (ASP) program conducted for the Ballistic Missile Defense Advance Technology Center (BMDATC) under contract DASG60-77-C-0111. This report presents the results of the test and evaluation of six additional subscale conical frusta conducted during the period from November 1978 through March 1979. The objective of this evaluation was to provide an increased structural data base for the assessment of the strength and stiffness properties of ultra-high modulus GY70/934 graphite/epoxy structures fabricated by the hand-laid gore, autoclave cure porcesses. The contractual effort was divided into three tasks.

Task 1 - Fabrication of Conical Frusta

A total of six subscale 7 degree half-cone angle conical frusta were fabricated from ultra-high modulus GY70/934 graphite/epoxy prepreg tape obtained from the Fiberite Corporation, Winona, Minnesota. These conical frusta were fabricated by hand layup, vacuum bagging, and autoclave cure processes. The first five frusta were processed using the process specification from the BMDATC ASP program. A sixth cone was fabricated to experiment with techniques to facilitate fabrication and improve part quality.

All conical frusta were inspected for conformance to drawing requirements. Non-destructive evaluation included radiographic and ultrasonic C-scan inspections. Material sampling included fiber/resin ratio and photomicrograph examination. This program demonstrated that ultra-high modulus graphite/epoxy shells can be built within acceptable missile structural design dimensional tolerances.

Recommendations for improvement in future manufacturing efforts include obtaining more uniform fiber distribution in the source material and the use of lower cure temperature resins and 104 fiberglass scrim cloth to minimize microcracking.

Task 2 - Static Testing of Frusta

To augment the test data obtained in Phase I of the BMDATC Advanced Structures Prototype Program, a total of six half-scale conical frusta were statically tested. Three cones were tested in axial compression at the Denver Division and three were tested at the Orlando Division to a combined load condition simulating the critical flight design loads.

The first two cones tested in axial compression (cones 3 and 5) were fabricated by the process specification according to contractual requirements. The test results for these cones are compared to analytical predictions and to the previous ASP cones in Table I. As shown, the strength of these cones exceeded the analytical prediction by 5 to 10 percent. Although the strength was less than the ASP cones, the compressive modulus was higher. The line stiffnesses (E x t) were in the same range as the ASP cones. The third axial load test was conducted on cone 6 which was fabricated using deviations from the specifications during the compaction cycles. This cone, with a wall thickness of 0.137 inch, failed in compression at 103,000 lbs. The compressive modulus was calculated to be 15.3×10^6 psi, and the maximum measured compressive strain was -2230 μin/in at the 100,000 lb load level. Although cone 6 met the strength goal (100,000 lbs), it fell 5 percent short of the stiffness goal of 2.2×10^6 lb/in.

TABLE I

Axial Load Test Results

Half-Scale Cone Fiber Layup (27 ply)	Prediction Basis: Laminate Theory	Prediction Basis: ASP Panel Tests	Test Results: Cone No.3	Test Results: Cone No.5	ASP Test Results (2 cones)
Fiber volume (%)	60-62	59	54.4	54.9	52.0
Ultimate strength (lbs)	100,000	100,000	105,000	110,000	116,000-120,000
Ultimate strain (μin/in)	-2500	-2680	-2830*	-2170*	-2540 to -2700*
Initial modulus (msi)	19.5	16.3	16.0	16.1	15.1-15.8
Thickness (in)	0.124**	0.135	0.138	0.143	0.145
Line stiffness (10^6 lbs/in)	2.42	2.20	2.21	2.30	2.19-2.29

*Largest measured compressive strain.

**Based on Fiberite's predicted ply thickness of 0.00460 inch.

To expand the structural data base, three cones (1,2 and 4) were tested to failure under combined loads producing a more realistic stress state, simulating an actual in-flight maneuver condition. Prior to testing, a structural analysis was conducted for the test condition and an ultimate strength of 129 percent of design limit load (DLL) was predicted. The results of these tests are shown in Table II. The demonstrated strengths in combined loading were 120, 130, and 140 percent of the DLL, which shows reasonable agreement with the analysis. The maximum axial strains, although not taken at the critical (internal) location, were approaching the allowable strain. The large transverse strains resulted from bending in the shell by the external pressure loading.

TABLE II

Combined Load Test Results

Half-Scale Cone Property	Analytical Prediction	Test Results		
		Cone No.1	Cone No.2	Cone No.4
Fiber volume (%)	60	51.5	56.5	53.9
Wall thickness (in)	0.135	0.137	0.132	0.144
Ultimate strength (% DLL)	129	120	130	140
Ultimate axial strain (μin/in)	-2060*	-2293	-2261	-2200
Ultimate Transverse Strain (μin/in)	±3300	-3367	-3400	-4800
*Critical strain is in the internal 45 degree plies.				

The evaluation of all test results including those of Phase I of the ASP program resulted in the following conclusions:

1 The half-scale GY70/934 graphite/epoxy conical frusta fabricated using process specification SPC 10720729-001 meet or exceed the design requirements.

2 Strength variations within ±8 percent of the average can be expected.

3 The analytical strength prediction technique produces reasonable although somewhat conservative results.

4 Axial compression strength of the conical frusta is sensitive to the wall thickness.

5 The deviations in the compaction process utilized to fabricate cone 6 did not improve the fiber/resin ratio or compressive strength.

Task 3 - Plan for Further Development

In Task 3, a plan was prepared that defines a development path leading to full scale validation of the application of graphite/epoxy composite structure technology to nuclear blast hardened BMD interceptor structures. Specific technical objectives of the plan are to provide the design, analytical and manufacturing processes, and techniques required to produce high quality full scale structures; determine a rapid production capability for composite structures; and to demonstrate through ground testing the capability of composite structures to meet BMD interceptor structures requirements.

A transition from subscale to full scale technology development is recommended so that full size structures are available in the Defense

Nuclear Agency (DNA) high explosive test series, MISTY CASTLE, which is scheduled for 1981-82. These tests will be an integral part of the full scale validation program for graphite/epoxy composite structures.

Structurally, the design requirements of both nuclear and NNK interceptors have some degree of commonality since the nuclear blast hardness and the forebody structure half-cone angle are the same. Since the step-up to full scale development requires new tooling, the composite structure program can be updated to reflect the new configurations and requirements with the least impact at this point in the program. An update of the structural configuration at this point in the program will also provide more realistic results in the full scale validation testing.

Prior to full scale development of composite structures, NNK warhead/structure interface testing at the subscale level is recommended to demonstrate the advantage of composite materials over metallic structures in this application, and to screen the relative performance of various types of graphite/epoxy materials.

The full scale development plan is comprised of the following major tasks:

1 Full scale design and analysis

2 Manufacturing technology development

3 Prototype structure fabrication

4 Technology validation demonstration.

In the full scale design and analysis task, a typical interceptor structural section that is representative of the future application of composite structures to advanced BMD interceptors in size, frame geometry, splice joints, and blast hardness will be designed. Structural analyses will be conducted to assure a minimum thickness design that will provide the required blast hardness.

Full scale manufacturing development is recommended to establish the manufacturing processes and tooling required for full scale fabrication. A rapid production capability should be determined and the required manufacturing processes and techniques identified. Production cost estimates using these processes should be provided.

Fabrication of approximately 29 full scale protype structures for subsequent validation testing is recommended. Integration of the prototype structure and heat shield would be accomplished on 11 test sections slated for shock and nuclear blast testing.

Full scale validation of the advanced structure design and manufacturing processes can be accomplished primarily in ground tests. The

structural components such as the primary shell, splice joints, and equipment and splice frames can be qualified by structural and dynamic shock testing to load levels simulating flight loading conditions. Nuclear blast pressure impulse would be simulated in both a (not yet identified) test facility and in the DNA high explosive test series MISTY CASTLE.

PREFACE

This report is prepared by Martin Marietta Corporation for the Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts under contract DAAG46-79-C-0006. This work is part of the program on development of hardened ABM materials under the direction of Mr. John F. Dignam, program manager. The AMMRC technical supervisor is Mr. Lewis R. Aronin.

This report covers work conducted from November 16, 1978 through March 16, 1979. The work was performed by personnel from Martin Marietta's Orlando and Denver Divisions. Mr. Loran M. Gilbert was the program manager. Principal contributors from the Orlando Division included:

Robert P. Hewitt	-	Task Leader
Frank H. Koo	-	Test and Analysis
Roland Williams	-	Stress Analysis

Principal contributors from the Denver Division included:

Robert D. Keys	-	Task Leader
Bernie Burke	-	Fabrication

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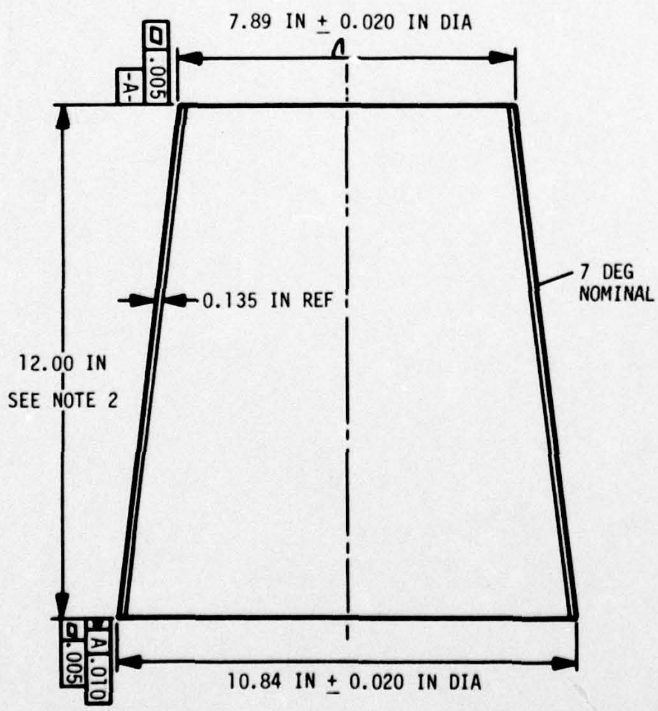
TABLES

1.0 INTRODUCTION

Short action time, highly maneuverable, blast-hardened advanced BMD interceptors impose challenging design requirements on the missile structures. Interceptor configuration studies over the last five years have identified the need for lightweight, stiff missile structures, especially for interceptors designed to engage maneuvering threats. To meet this challenge, the Army Materials and Mechanics Research Center has conducted research and development on advanced materials including Beryllium, metal matrix composites, and resin matrix composites. In the last category, ultra-high modulus (UHM) graphite/epoxy composite structures have been under evaluation and subscale development since 1973 (Reference 1).

In 1977, the Ballistic Missile Defense Advanced Technology Center (BMDATC) initiated a multi-year Advanced Structures Prototype program to develop and validate the technology base for advanced interceptor structures and heat shields. Phase I of this program (contract DASG60-77-C-0111) conducted by Martin Marietta, resulted in the development of a process specification for the manufacture of UHM GY70/934 graphite/epoxy conical shells. Two conical frusta were fabricated and evaluated by axial compression testing (Reference 2).

The test section was a half-scale frustum (Figure 1-1) representing the aftermost shell of the separable glide body on the Advanced Terminal Defense Interceptor (ATDI) candidate 8 interceptor (Reference 2). The design layup and fabrication process was shown in these tests to produce frusta that satisfy the design requirements of 100,000 lbs axial compressive strength and 2.2×10^6 lb/in line stiffness.



NOTES:
1. GY70 FIBERITE 934 PLY LAMINA LAYUP (27 PLIES) $(0_2/45/90_2/-45/0_2/45/90_2/-45/\underline{0_3})_S$
2. THIS LENGTH WHEN FABRICATED TO BE 12.2 INCHES MINIMUM. TRIM TO B/P SIZE TO REMOVE IRREGULARITIES.

Figure 1-1. Half-Scale Conical Frustum

The primary objective of the Composite Structures Test and Evaluation program is to provide an increased structural data base for the evaluation of the strength and stiffness properties of GY70/934 graphite/epoxy conical frusta fabricated by the hand-laid gore, autoclave cure processes. This objective will be accomplished by testing additional half-scale conical frusta utilizing the design, manufacturing process specifications, and test procedures of the BMDATC sponsored Advanced Structures Prototype program. Additionally, this data base will be expanded to include combined load testing correlated to analytical predictions to demonstrate the requirement of an ultimate factor of safety of 1.25 for the critical design condition.

A secondary objective of this contact is to provide a plan for future technology development with a full scale demonstration of graphite/epoxy prototype structure as a goal. This plan will be based upon results of this and other related AMMRC contracts, and will address validation testing to define strength, stiffness, and shock and blast response of the full scale prototype structure.

2.0 TASK 1 - FABRICATION OF CONICAL FRUSTA

2.1 Material

Shell fabrication material (Celanese Corporation GY70 ultra-high modulus unidirectional fiber impregnated with Fiberite Corporation 934 high temperature resin system) was purchased from Fiberite in the form of spooled 3 inch wide tape with release paper backing. The material was purchased using Martin Marietta specification ANA 74700314-001 Rev B, Type 5, Class 4, and was delivered in eight separate rolls with the manufacturer's certification and test data as shown in Tables 2.1-I and II.

During a visual receiving inspection of the prepregnated material, random areas of lateral fiber separation were found along the length of the tape. All of this separation occurred on one side of each roll, with separations to a maximum of 0.060 inch appearing across approximately one-third of the tape width. The remaining two-thirds of the tape width was of very good quality-well aligned, tightly packed, uniformly coated, and contained very few loose pick-up fiber strands.

TABLE 2.1-I

Unidirectional GY70 Material Properties

Material: Fiberite Hy-E 1534, 3.0 Inch Tape Lot No. C9-045, Quantity: 41.2 lb								
Roll No.	1	2	3	4	5	6	7	8
Resin solids (%)	39.3	39.5	39.4	37.6	42.7	43.0	41.7	42.4
Volatile content (%)	0.7	0.5	0.4	0.5	0.4	0.4	0.4	0.4
Laminate flow (% at 50 psig)	17.4	17.0	16.1	18.2	23.7	22.9	21.0	19.0
Gel time (min at 177°C)	8.9	9.0	9.3	8.8	8.3	9.1	8.8	8.6
Tape lineal feet	376	460	458	482	430	415	470	475
Net weight (lb)	4.2	5.2	5.4	5.4	4.9	4.8	5.6	5.7
Tack and drape test	Pass							
Specific gravity	1.79							
Fiber volume (%)	64.92							
Flexural strength (psi)	Room temp 350°F			131,744* 115,614*				
Flexural modulus (10^6 psi)	Room Temp 350°F			38.61* 38.78*				
Horizontal beam shear (psi)	Room Temp 350°F			6040 5652				
Cured ply thickness (in)				0.0045				
Date of manufacture				09/22/78				
Shelf life	6 months at 0°F maximum							
Meets specification ANA 74700314-001, Rev. B, Type 5, Class 4.								
Infrared scan furnished								
*Values normalized to 63% fiber volume								

TABLE 2.1-II

Celanese Corporation GY70 Fiber Data

Lot	Tensile Strength (ksi)	Tensile Modulus (10^6 psi)	Density (g/cc)
218(40)	263.1	77.9	1.991
218(39)	263.1	77.9	1.988
217(12)	257.5	77.5	1.998
218(38)	263.1	77.9	1.988
217(11)	257.5	77.5	1.996
218(04)	243.5	77.7	1.994
223(19)	290.4	77.9	1.988
223(26)	229.0	74.0	1.988

Overall, the material was in better condition than that used on the first two cones in Phase I of the ASP development effort, but still below the uniformity desired. Due to the large amount of marginal tape material, selective trimoff would not have yielded enough usable material to build five cones. It was decided, therefore, to build cone shells with the material as supplied to more closely represent production fabrication.

Resin content tests were not taken at the beginning and end of each roll as originally planned, since previous experience had shown the resin content to vary locally along the roll length. Without multiple samplings of each roll, the average resin content could not be more accurately determined than the test values stated by the manufacturer (See Table 2.1-I).

2.2 Fabrication

Five conical shells were produced using the fabrication process detailed in the preliminary manufacturing process plan evolving from contract DASG60-77-C-0111 (Appendix A). An extra cone (the sixth) was also fabricated to investigate possible improvement in the process which might avoid some of the difficulties experienced while fabricating the first five, and thus potentially yield a better product.

Rolls of 3 inch wide prepregnated tape material were removed from the storage freezer as needed. These rolls were then warmed (in their wrapping) to room temperature and were placed on tedlar film over the polyethylene cutting board (Section 5.2.1.4 of Appendix A). By doubling the height and extending the length of the tape layout on the cutting board, an approximate 10 percent savings in prepregnated graphite material was realized, since less edge trim allowance was required with the extended layout. After cutting the material (Figure 2.2-1), the quadrant sections were marked for identification and then stacked flat with tedlar facing against paper backing. The material was then packaged in polyethylene bags for refreezing until needed. Each bag contained enough material of a given ply orientation to build the one cone designated on the bag. Traceability of the plies in each cone was therefore established.

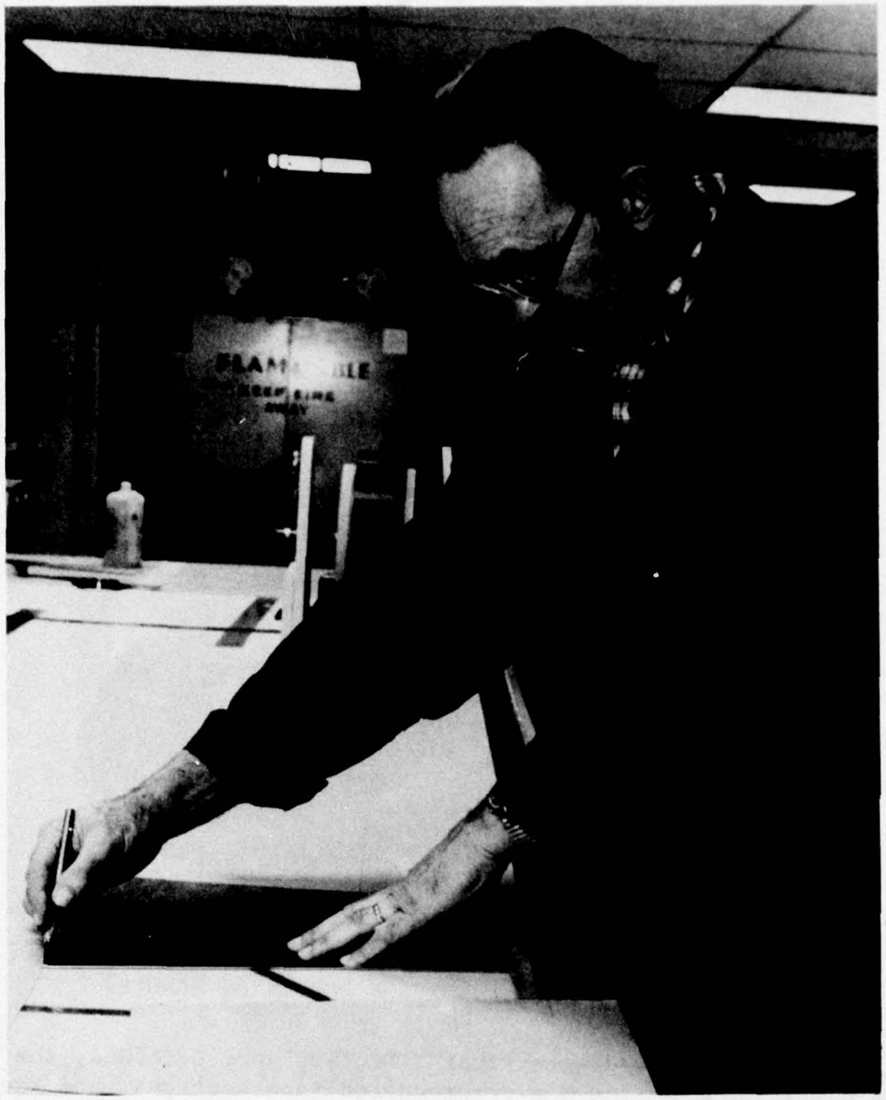


Figure 2.2-1. Cutting of Oriented-Ply Gore Segments using Profile Template

Two graphite composite layup and compaction male mandrels such as the one shown in Figure 2.2-2 were used for the laminate layup sequences. These conical mandrels had a 7 degree taper (required for the laminate shells) and were approximately 19 inches high. Mandrel surfaces were prepared per the process plan and were overwrapped with 1 mil of unperforated FEP film. Enough prepregnated quadrant (gore) sections for 4 hours of fabrication were warmed and removed from their plastic bags. The remaining sections were placed back in refrigeration for future use.

Figure 2.2-2. Male Layup and Debulking Mandrel

Beginning with the 0 degree fiber direction gore sections, the tedlar facing film was removed from the prepregnated tape sections, and the 15 inch high gore quadrants were positioned on the mandrel. They were then edge-indexed for azimuth using a fixture template, vertically aligned, smoothed down against the mandrel, and the joint trimmed as shown in Figure 2.2-3. Through the first nine plies, the mandrel layup procedure was conducted according to the process plan. Joint gap allowance was increased in the 90 degree fiber orientated layers starting with the tenth ply, with gap allowances of 0.040 to 0.060 inch to permit joint closure during compaction. Gore section joints of other directions did not require the extra joint gap allowance, but bulging due to edge contact in the 90 degree oriented plies was observed after compaction when less joint allowance was permitted. Although this bulging was smoothed out after compaction, there was concern that the GY70 fiber might be broken or disoriented in the bulge regions after smoothing, and that a subsequent loss in the cured shell strength might result at the beginning of the layup sequence. In an effort

to prevent layup climb up the mandrel during compaction, the first 0 degree oriented layer for cone 5 was cut 1 inch longer at the lower end and taped to the mandrel rather than to the 1 mil teflon release layer around the mandrel. By preventing upward shift of the layup, the contacting of the 90 degree joint faces could be avoided while using only enough joint gap allowance, (0.020 to 0.040 inch) to correct for circumferential closure during compaction. The tape-secured inner layer did not provide sufficient restraint to eliminate indications of layup climb, but did reduce the magnitude of the shift.

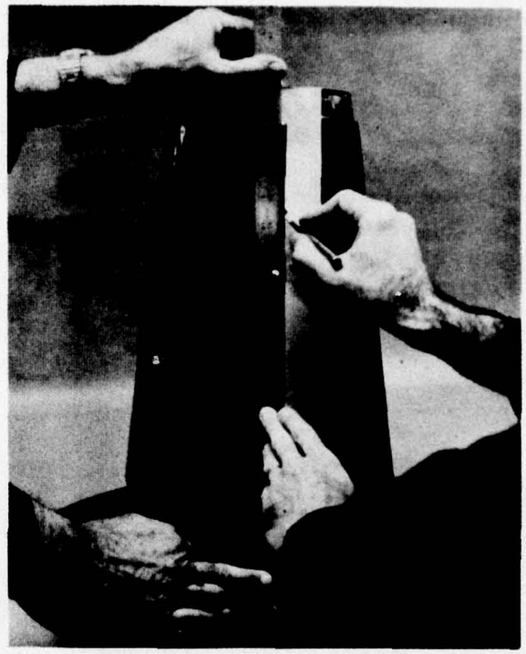


Figure 2.2-3. 0 Degree Fiber Direction Gore Being Trimmed to Fit at Typical Butt Joint

For the first five cones produced, three compaction cycles were used during laminate fabrication: 1) the first after the 10th ply of layup with average radial compaction of 16 mils; 2) the second after the 20th ply of layup with average radial compaction of 25 mils; and 3) the third after the 27th (final) ply of layup with average compaction of 11 mils. All thermal compactions were done on the male mandrels in accordance with Section 5.2.1.5d of the process plan (Appendix A) using internal vacuum and 50 psig external pressure for 15 minutes at 150°F. Process changes were made in the sixth cone.

Cures on the female mandrel were made as detailed in Sections 5.3.2.6 and 5.3.3 of Appendix A. Since the resin content of cone 1 was high, a slight modification in bleed technique was made beginning with cone 3 and continuing through cone 6. To lower the resin content slightly on the finished product, 120 glass cloth was substituted for the 112 cloth.

Ultrasonic testing of cones 2 through 6 was accomplished prior to trimming off the end rings to minimize moisture pickup in the exposed laminate edges during water-immersed C-scan inspection. All shells were scheduled for a 12 to 16 hour bakeout at 125 to 140°F to reduce absorbed moisture prior to test. The 828 chopped fiberglass composite potting (Figure 2.2-4) used to stiffen the free ends of cones 3, 5 and 6 for the axial compression tests was trowelled into place inside and outside the shell rim at the same time on the bottom end. Because of the possibility of resin contraction stresses cracking the graphite laminate, the outside rim on the top end was potted separately and allowed to set before the inside ring was cast. A post-cure bakeout at 125 to 140°F of the end rings on cone 3 resulted in enough thermal and resin cure shrinkage stresses to cause four areas of inner 0 degree ply delamination. Three of these areas were 1 inch long while the fourth was a 1/4 inch long delamination of the graphite shell upper rim. Since the delamination depth was apparently shallow, a rebond mixture of epoxy 828 resin with 9 percent DTA catalyst was applied to the rim delamination areas and then subjected to a vacuum for 1/2 hour at room temperature to gain penetration into the interior regions of the delaminations. After removal from the vacuum chamber, the fill resin mix was allowed to cure for more than 72 hours at room temperature before further handling. The resin filling method stabilized the structure's rim adequately to continue through instrumentation and test completion.

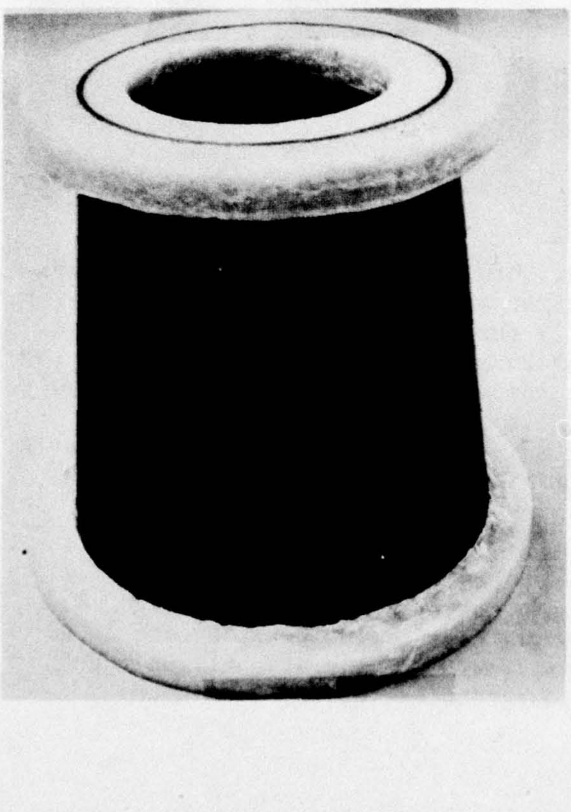


Figure 2.2-4. Test Shell with Potted End Rings

2.3 Inspection

In addition to dimensional measurements, nondestructive test (NDT) evaluations on all shells included visual inspections for foreign materials, gaps and laps, wrinkles, breaks and cracks, delaminations, porosity, resin starved and resin rich areas, disoriented fibers, and microscopic inspections of samples from the trim-off ends as detailed in Section 5.1.1 of Appendix A. Ultrasonic C-scans and radiographic inspections were also utilized for each shell.

2.3.1 Measurements

A summary of dimensional and fiber content values for each of the conical frusta is presented in Table 2.3-I. Height and parallelism readouts were taken on a surface table using conventional height gage and dial runout indicator techniques. Shell thicknesses were checked with ball-tipped micrometers due to the texture of the interior surfaces. Thicknesses were measured at 0, 90, 180, and 270 degree orientations at the top and bottom rims of the shells.

TABLE 2.3-I

Dimensions and Fiber Content
Values of Conical Frusta

Measured Values		Cone Frusta Number					
		1	2	3	4	5	6
Top rim diameter (in)							
	min	7.897	7.87	7.903	7.900	7.898	7.850
	max	7.907	7.88	7.903	7.900	7.900	7.860
Bottom rim diameter (in)							
	min	10.814	10.819	10.824	10.823	10.825	10.860
	max	10.827	10.822	10.830	10.830	10.833	10.860
Shell height ($\pm$0.002) (in)		11.974	11.998	12.029	12.020	12.019	12.005
Top thickness (in)							
	min	0.135	0.131	0.132	0.141	0.144	0.136
	max	0.139	0.135	0.143	0.145	0.145	0.139
Bottom thickness (in)							
	min	---	0.131	0.134	0.141	0.141	0.135
	max	---	0.134	0.141	0.147	0.143	0.139
Fiber volume (%)							
	top	51.3	56.2	54.2	53.7	54.5	52.5
	bottom	51.2	56.8	54.7	54.2	55.2	52.4

2.3.2 Visual Inspection

All conical frusta appeared smooth and regular on the exterior with uniform glassy resin finishes. Reinforcement ply orientations and quadrant joint lines were readily visible on the surface. The supplier's gripping patterns, imprinted on the tape during prepregnation or slitting operations, were visible beneath the surfaces on the finished parts as shown in Figure 2.3-1.

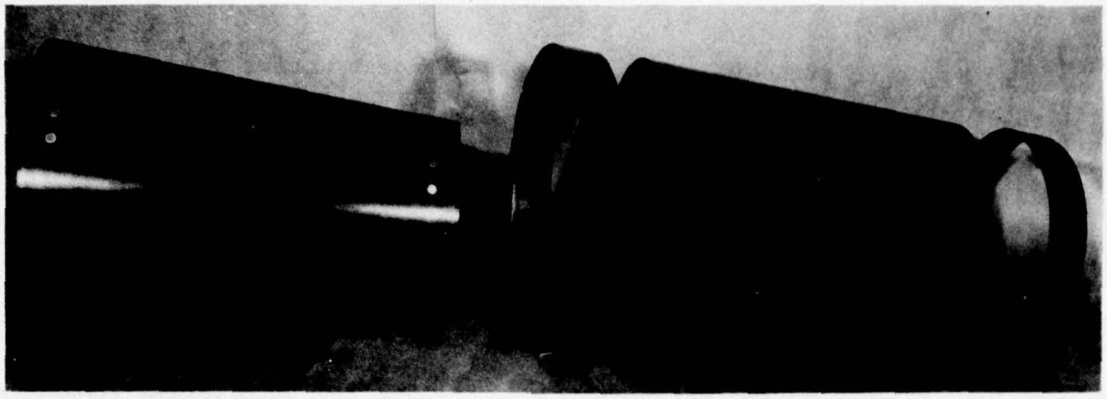


Figure 2.3-1. Finished Laminates Before and After End Ring Trimoff

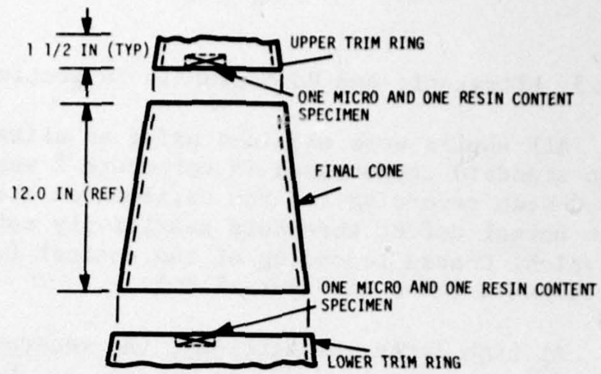
Interior wall surfaces showed some texturing due to print-through from the 181 fiberglass cloth bleeder layer behind the smooth-finish dacron used during cure. Imprints of the 1-1/2 mil tape used to join the perforated FEP release film edges were visible on the inside walls as well as on the overlap regions of the dacron facing cloth. Where wrinkling of the backup cloth or FEP film occurred during cure, narrow lengthwise indentations usually one or two per cone up to 10 mils deep were evident on interior walls.

Microexamination of sections cut from trimoff rings, Figures 2.3-1 and 2.3-2, showed that uniform microcracking occurred along exterior 0 degree oriented plies and, with lesser frequency, along the interior 0 degree plies. These microcracks, which do not extend beyond the 0 degree oriented plies, are shown in Figure 2.3-3. Microcracks are characteristic of ultra-high modulus fibers in 350°F curing resin systems. The frequency of microcracks in the 0 degree plies of the conical frusta ranged from 11 to 33 per inch of circumference.

All microsection examinations showed laminate construction meeting the microinspection criteria of the process plan with the exception of microcracking, as discussed. Occasional porosity was found along the internal 45 degree ply boundaries on cones 1,2, and 5; however, the pores were minimal in quantity, less than 0.001 inch in size and far below acceptance maximum limits.

Because of non-uniformity of fiber packing along one edge of the source material, some deviation from the optimum of tightly packed reinforcement fiber was evident within single ply local regions in the microsections. Separation between two bundles of fibers in such areas were filled with resin and were acceptable by all inspection criteria. Such regions, however, generate an overall increase in the resin content of the laminate with a resulting decrease in elastic moduli, since less reinforcement fiber is contained in a laminate of fixed ply construction.

Figure 2.3-2. Locations of Inspection Sample Specimens



Cone 3 Upper Rim

Cone 3 Lower Rim

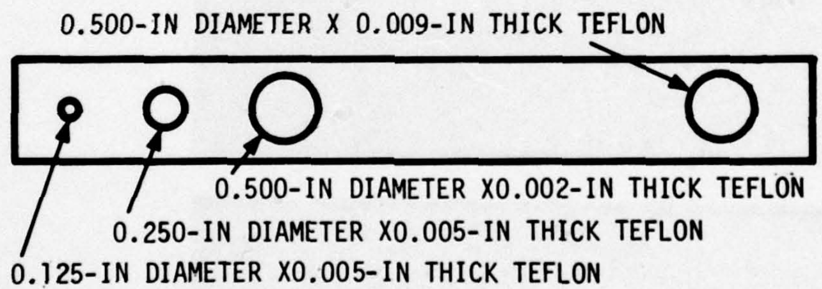
Figure 2.3-3. Cone 3 Photomicrographs (20X)

2.3.3 Ultrasonic and Radiographic Inspections

All shells were examined using an ultrasonic C-scan. The same calibration standard coupon used in Reference 2 was used for the current testing. The C-scan recording for the calibration standard is shown in Figure 2.3-4 with normal defect threshold sensitivity settings derived from the standard. A typical C-scan recording of the conical frusta at the normal intensity settings is shown in Figure 2.3-5.

At high intensity settings, the recordings are very "noisy" since the ultrasonic signal response is altered by changes in material density, thickness, and surface irregularities, in addition to defects. No signal discontinuities due to internal cracks or delaminations were shown on C-scan recordings of the six shells at normal (calibration level) intensity settings.

At the high intensity settings, a number of signal discontinuities were recorded, most of which were traceable to internal wall indentations and local waviness. Local density changes in the upper 1-1/2 inch end trimoff ring regions of cones 3 and 5 were detected at high intensity settings. Three out of the four delaminations of the inner two plies of cone 3, which occurred during cool-down after end ring baking, coincided with discontinuities in the high intensity C-scan recording near the upper rim.



(a) Reference Standard Lamina Sketch

(b) Baseline C-Scan Recording

Figure 2.3-4. Ultrasonic C-Scan Calibration Standards

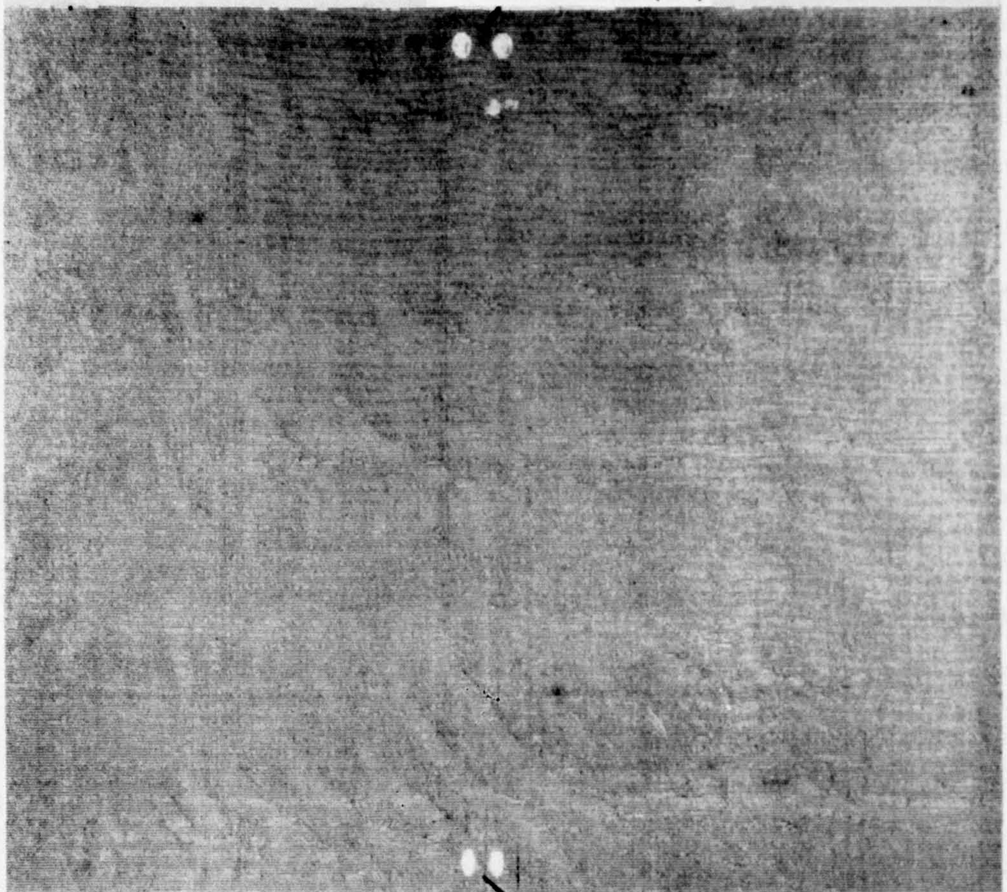


Figure 2.3-5. Ultrasonic C-Scan of Graphite/Epoxy Cone

High resolution X-ray inspection of all shells was conducted. Shots were taken in a minimum of four normal orientations and typically six tangential (sloped edge) views of each shell. Internal ply joint lines could be discerned and the uniformity of the staggered joint indexing was visible. Occasional small (spherical porosity) voids of less than 0.010 inch diameter were detected, but no indications of delaminations or cracks were evident in any of the radiographs.

Small aluminum trace fragments from the gore section layup fit and trim cutting operations, where an aluminum backup strip was used for knife cuts of the ply edges, were evident in the radiographs. These fragments were extremely small (specks) and could not affect the structural performance of the laminates.

Overall, the radiographic inspection of the shells was very effective as a process control verification method and showed the laminates to be of high quality construction. Radiography is of limited value in detecting small cracks unless they are collimated in the direction of the beam. Similarly, delaminations can effectively be detected only in the tangential views of the shell walls.

2.4 Process Improvement

Several options for potential product improvement and improved processing techniques were noted during fabrication of the first five conical shells. Three of these ideas were used in the fabrication of the sixth (extra) conical shell.

The first processing change used in the fabrication of the sixth cone was the addition of room temperature atmospheric pressure compactions at intermediate points during fabrication, while retaining the three thermal compaction cycles previously used. Atmospheric pressure (12 psia at the laboratory altitude) was utilized to help compact the layup at the 5th, 15th, and 25th ply buildup points without an added thermal cycle, since the gel time of the 934 resin system was only 8 to 9 minutes at cure temperature. The thermal compaction cycles used on the first five conical shells were retained at the 10th, 20th, and 27th ply buildup points.

Room temperature compaction was accomplished using the same RTV 700 silicone rubber bag as detailed in the process for thermal compactions; however, the room temperature compaction required only 5 minutes maximum time with the bag evacuated to 22 or more inches of Mercury. Figure 2.4-1 shows the compaction step in progress with the layup profile visible beneath the evacuated rubber bag. The intent of the extra compactions was to "iron" the layup more firmly together without excessive loss of fabrication time and resin flow properties which would have been incurred with extra thermal cycles. Less total material shift and thickness change during the thermal compaction was encountered following the intermediate step compactions, and less reinforcement fiber distortion was anticipated.

The second change in processing for the sixth cone was in the use of externally applied force to offset the climb displacement of the layup on the tapered mandrel during compaction. By eliminating the upward displacement of the layup, less circumferential closure of the 90 degree oriented ply joints would be encountered and tighter fitting joints would result without the risk of fiber damage from bulging and subsequent smoothing as previously encountered.

Calculations were made showing an imbalance in the force systems acting on a laminate layup at the FEP film/tapered mandrel wall interface during compaction. The net result was an upward force of less than 16 lb acting to slide the composite along the mandrel when one-atmosphere compactions were used. Large displacements were prevented by the tightening of the rubber bag and breather cloth layers within the enclosure. To offset the upward displacement force, a deadweight loading was applied

against an exterior 7 degree conical shell fitting over the silicone rubber bag. A 20 pound weight was applied to the external cone for the one-atmosphere compactions and a 40 pound weight for the 50 psig (five atmospheres at 6000 foot altitude) autoclave thermal compactions. The deadweight system prevented any measurable displacement of the layup on the mandrel throughout the six compaction steps. No added joint gap allowance was necessary for the 90 degree oriented plies and no evidence of bulging was seen. The method would be especially useful for fabrication of conical sections with tapers greater than 7 degrees.

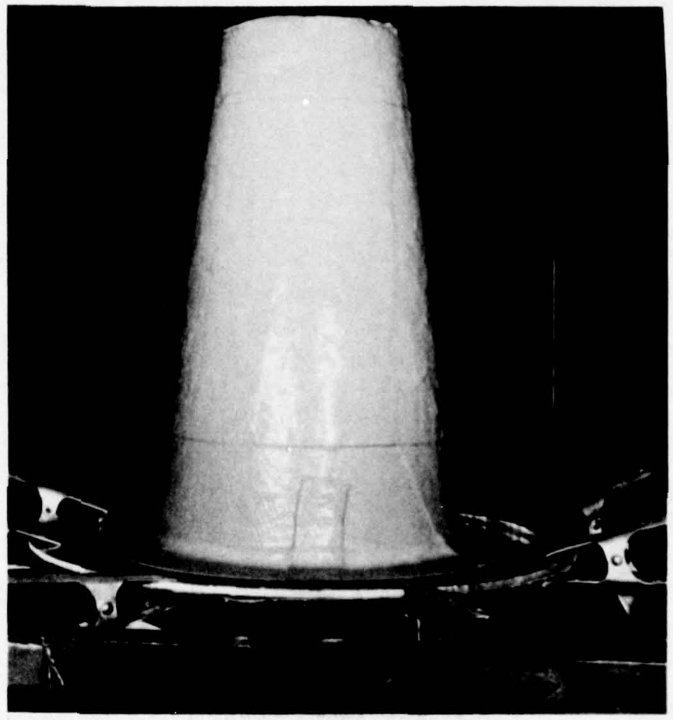


Figure 2.4-1. Evacuated Silicone Rubber Bag Compaction of a Layup on a Male Mandrel

The third change in processing was in the use of the 120 glass cloth instead of the 112 cloth in the bleeder layer during cure. This change was incorporated earlier for cones 3 through 6 to reduce the resin content to the desired range of 42 to 44 percent. More resin bleed was attained, but due to the fiber separations in the source material, the total bleedout was necessarily limited to prevent structural voids and low interlaminar shear properties near the interior shell wall surface. Better source material would permit closer control of resin content minimums.

As a result of the process changes outlined, the cone 6 conical shell microsection inspections showed a more tightly compacted interior microstructure than the average of the preceding laminates. Near the surfaces, the laminate's appearance was the same as the others. Porosity appeared no different than for the originals. Ultrasonic C-scan and X-ray inspections showed the laminate to be of good quality with very good joint gap control throughout and no discernable defects.

3.0 TASK 2 - STATIC TESTING OF FRUSTA

3.1 Axial Load Testing

3.1.1 Test Objectives

The objective of the axial load testing was to provide structural data for the evaluation of the subscale manufacturing processes by determining the strength and stiffness properties of the subscale conical frusta. The data obtained from these tests augment that from the previous Advanced Structures Prototype program (Reference 1).

3.1.2 Test Procedures

Two half-scale conical frusta (cones 3 and 5) which were fabricated per the process plan in Appendix A were tested to failure in axial compression in conformance with the conical shell test plan (Reference 3). An additional cone (No. 6) which was fabricated using deviations from the process plan (Section 2.4) was also tested to failure. To minimize flexural effects at the free ends, all conical frusta to be tested in axial compression were reinforced with 1 inch deep end rings of 828 epoxy/chopped fiberglass composite potting.

The axial load testing was performed on the MTS model 810 closed loop control servo-hydraulic test machine (1000 kip capacity) located in cell P2 of the Denver Division structural test facility. Heavy face plates were attached to the machine test heads and a circular steel load distribution plate was placed between the upper loading head and the test cone. This test setup is shown in Figure 3.1-1. Final alignment of the setup was accomplished by placing graduated shim leaves between the upper loading head faceplate and the circular load distribution plate. Load uniformity was monitored by the output reading of the upper set of axially oriented strain gages and adjusted as required. Load alignment was conducted at load level increments from 10,000 to 40,000 pounds. Typically, the balance was adjusted to five percent or less before the test was continued to the higher load levels. Loading was adjusted manually be set-point control at a rate of 10,000 pounds per minute or less to 10,000 pound incremental load levels, where loading was held until strain recording was completed before resumption of loading to the next level. 10,000 pound increments were used from 0 to 100,000 pound loading, then 5,000 pound increments from the 100 kip level until failure.

The test cones were instrumented with Micro-Measurements type EA250-06-120 unidirectional and type CEA13-250 UR-120 Rosette (0/45/90 degree) strain gages. Temperature compensation was attained with identical bridge-completion gages mounted on graphite composite trim-off material. Axial deflection measurements were taken using deflection sensors located 180 degrees apart. These sensors were used to feed averaged test deflection signals to an X-Y plotter which recorded deflection to failure. Strain gage outputs were recorded on a B&F Model SY256-56 digital data acquisition system and a Baldwin-Lima-Hamilton strain indicator with two switch and balance units.

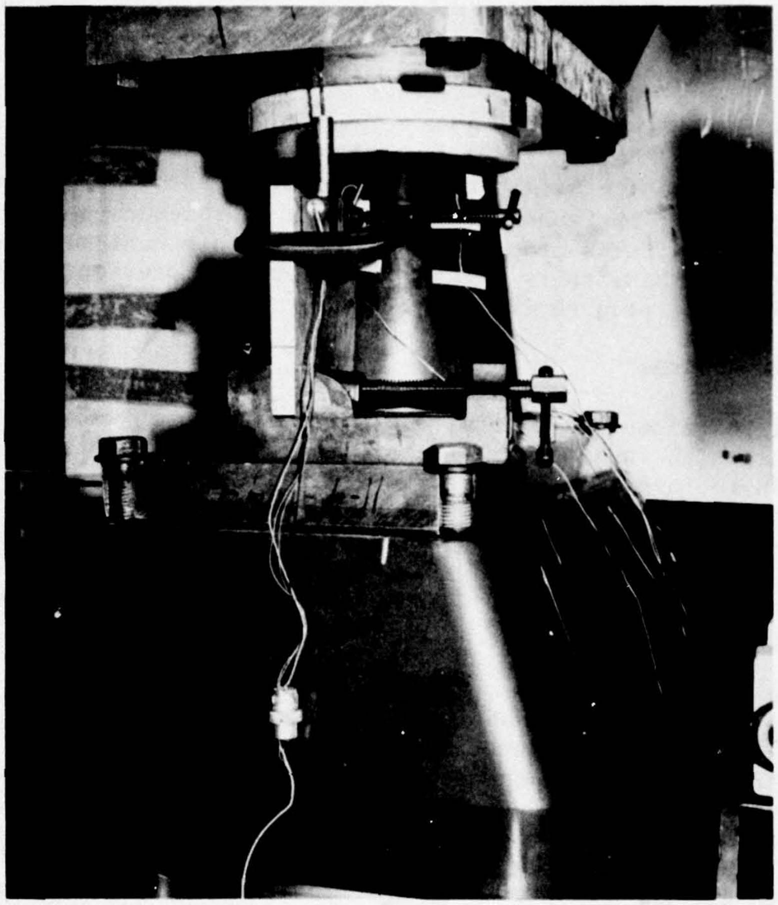


Figure 3.1-1. Cone 6 Loaded in
1000 kip Test Machine

3.1.3 Test Results and Data Analysis

Cones 3 and 5 failed in compression while holding the load for data recording. Cone 3 emitted cracking noises prior to failure at 105,000 pounds. Cone 5 emitted only one noise earlier in the test and failed suddenly at 110,000 pounds.

Cone 6, instrumented with only nine axial type strain gages, failed suddenly at 103,000 pounds while increasing the load from 100,000 to 105,000 pounds. All failure modes were of the same appearance as shown in Figure 3.1-2. The fracture lines are circumferential, closed path fractures which travel around the cones 1 to 2 inches from the upper (small) ends. General fragmentation of the test sections was prevented by using the test machine in stroke control mode for cones 3 and 5, and adjusting the machine ram to within 3/16 inch of its bottomed-out stroke limit for cone 6, which was tested in load control mode.

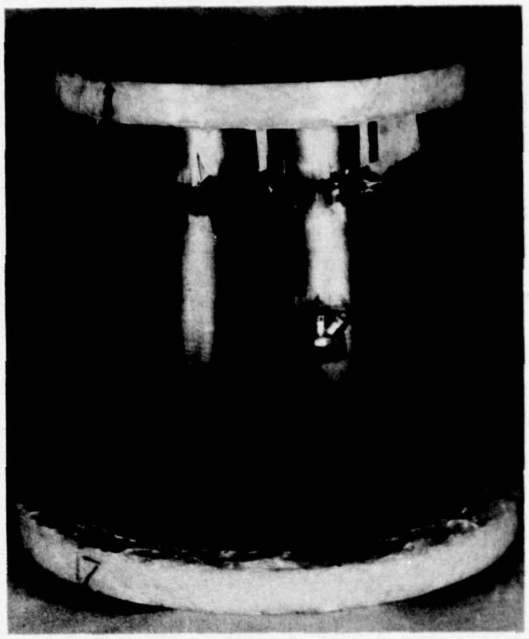


Figure 3.1-2(a). Conical Shell 3 After Axial Compression Test to 105,000 lb

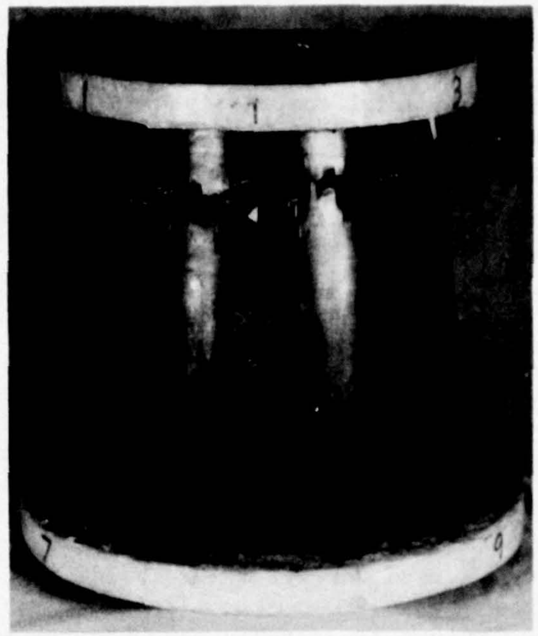


Figure 3.1-2(b). Conical Shell 5 After Axial Compression Test to 110,000 lb

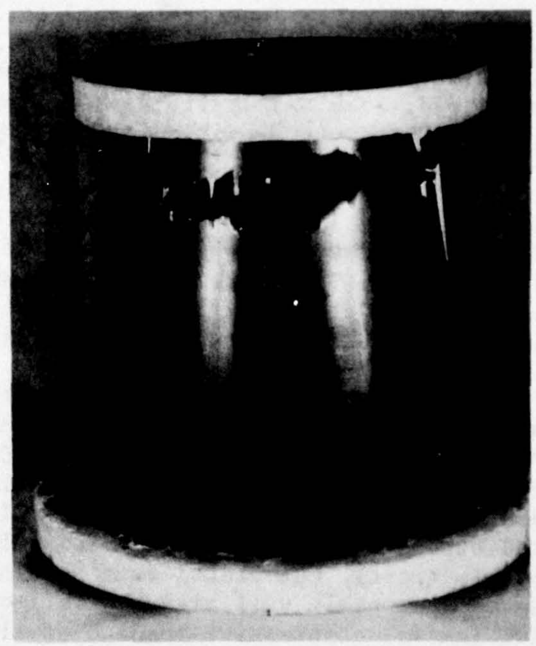


Figure 3.1-2(c). Conical Shell 6 After Axial Compression Test to 103,000 lb

3.1.3.1 Axial Load Test Data Analysis

A predicted shell failure load for the half-scale conical specimens tested in axial compression was obtained during Phase I of the ASP program. The calculated ultimate shell strength was obtained using the following considerations:

1 The compressive strengths developed by panel 4 which are described in Section 2.4.3 of Reference 2,

2 The laminate strength degradation due to gore pattern induced fiber angle misalignment,

3 Edge moments caused by the 7 degree cone half angle and the reinforcing rings. The edge moment factor was obtained by using a TEXGAP finite element model of the half-scale cone which included the chopped glass/epoxy reinforcing end rings. Based on these factors, the predicted ultimate axial compression load for the test cones was 100,000 pounds and the predicted longitudinal line stiffness was 2.2×10^6 lb/in.

Thirty-nine strain measurements were taken on cones 3 and 5 during the axial load testing. The strain gage locations are shown in Figure 3.1-3. The strain data for cone 3 are presented in Figures 3.1-4 through 3.1-6 and the strain data for cone 5 are presented in Figures 3.1-8 through 3.1-10. In addition, two axial deflection measurements were taken at locations diametrically opposed using low voltage deflection transducers. These deflection data are presented in Figures 3.1-7 and 3.1-11 for cones 3 and 5, respectively. The strain data followed trends exhibited in the previous test series of the ASP contract; e.g., the largest strains occurred at the smaller section (C-C), and the compressive strains were slightly non-linear with load. The axial strains also indicated that cone 5 was slightly stiffer than cone 3. This is also indicated by a lower cone deflection.

The strain gage data on cone 5 indicate that an initial local failure occurred at a 100,000 pound load at the inner plies near the small end. This is evidenced by a sudden drop of strain on two of the three axial strain gages (Figure 3.1-10). Examination of the outside strains at this location indicates that part of the load was transferred to the outer plies as shown by a sudden increase in strain at the same load level.

A summary of the axial load test results is presented in Table 3.1-I, along with the basis for strength predictions. This table also provides, for reference, the range of results from the previous test series conducted under BMDATC contract DASG60-77-C-0111. These data show that cones 3 and 5 are more compact, have a higher modulus of elasticity, and have demonstrated strengths above the predicted value. The initial compressive modulus of elasticity, calculated from strain data at the 20,000 pound load level, agree reasonably well with the deflection data in Figures 3.1-7 and 3.1-11. The initial compressive modulus of elasticity is less than the theoretical value. This is expected since the theory assumes perfect fiber alignment,

whereas in practice a four-gore pattern of "zero" degree fibers actually has an average angular alignment of 2.75 degrees. The measured modulus from test data closely follows the rule-of-mixtures method of predicting laminated composite stiffness. The average failure load for all cones (including the ASP cones) is 112.7 kips and the variation of this data sampling is within ±7 percent.

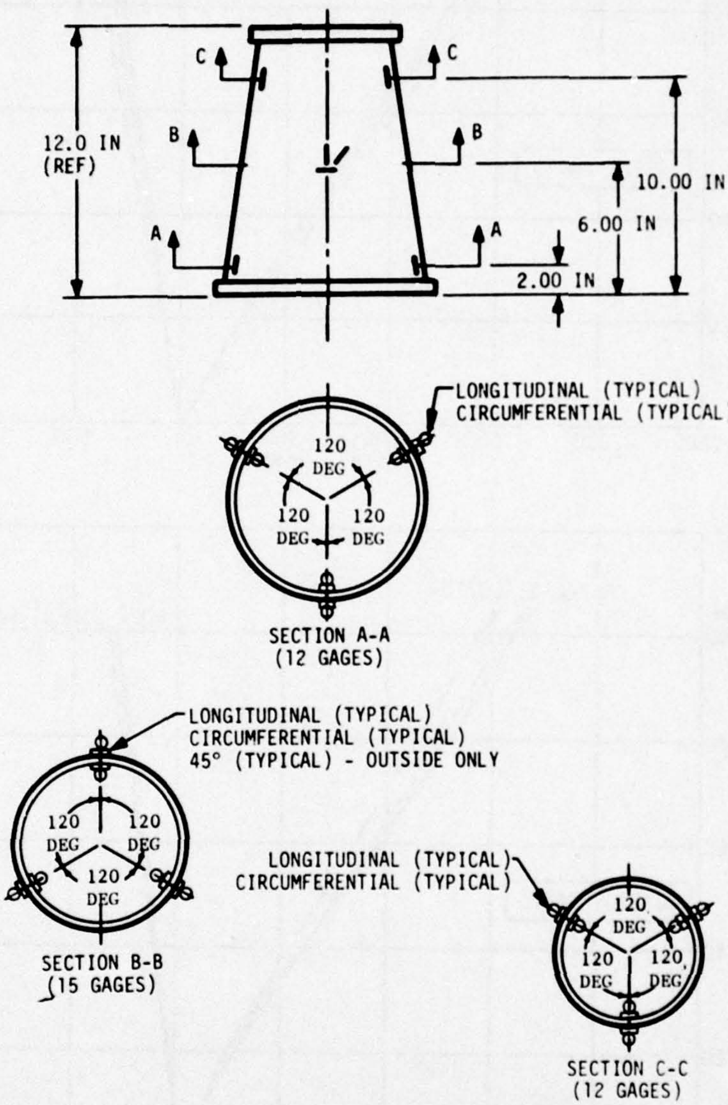


Figure 3.1-3. Strain Gage Locations

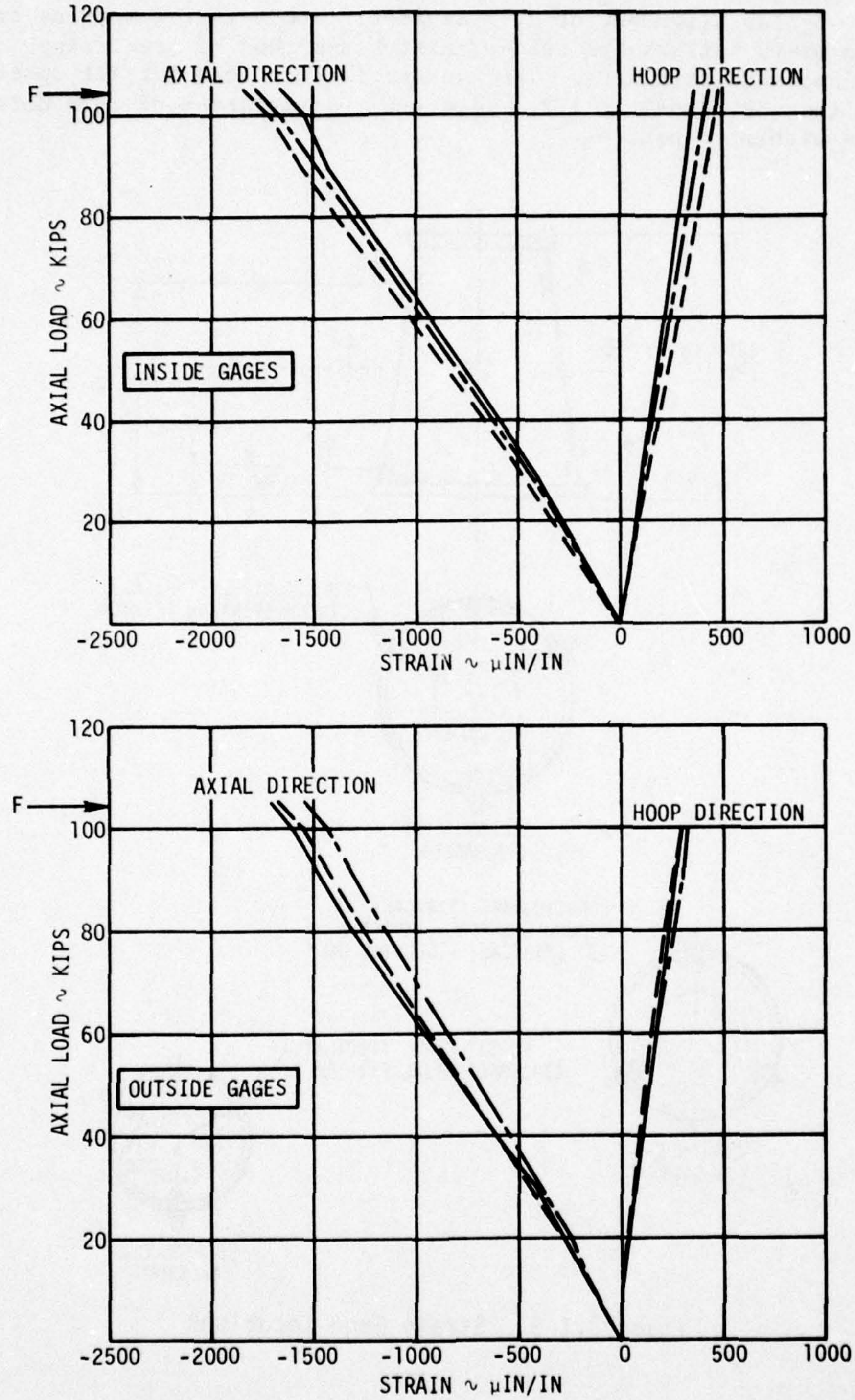


Figure 3.1-4. Cone 3 Axial Load Test - Section A-A
Strains versus Test Load

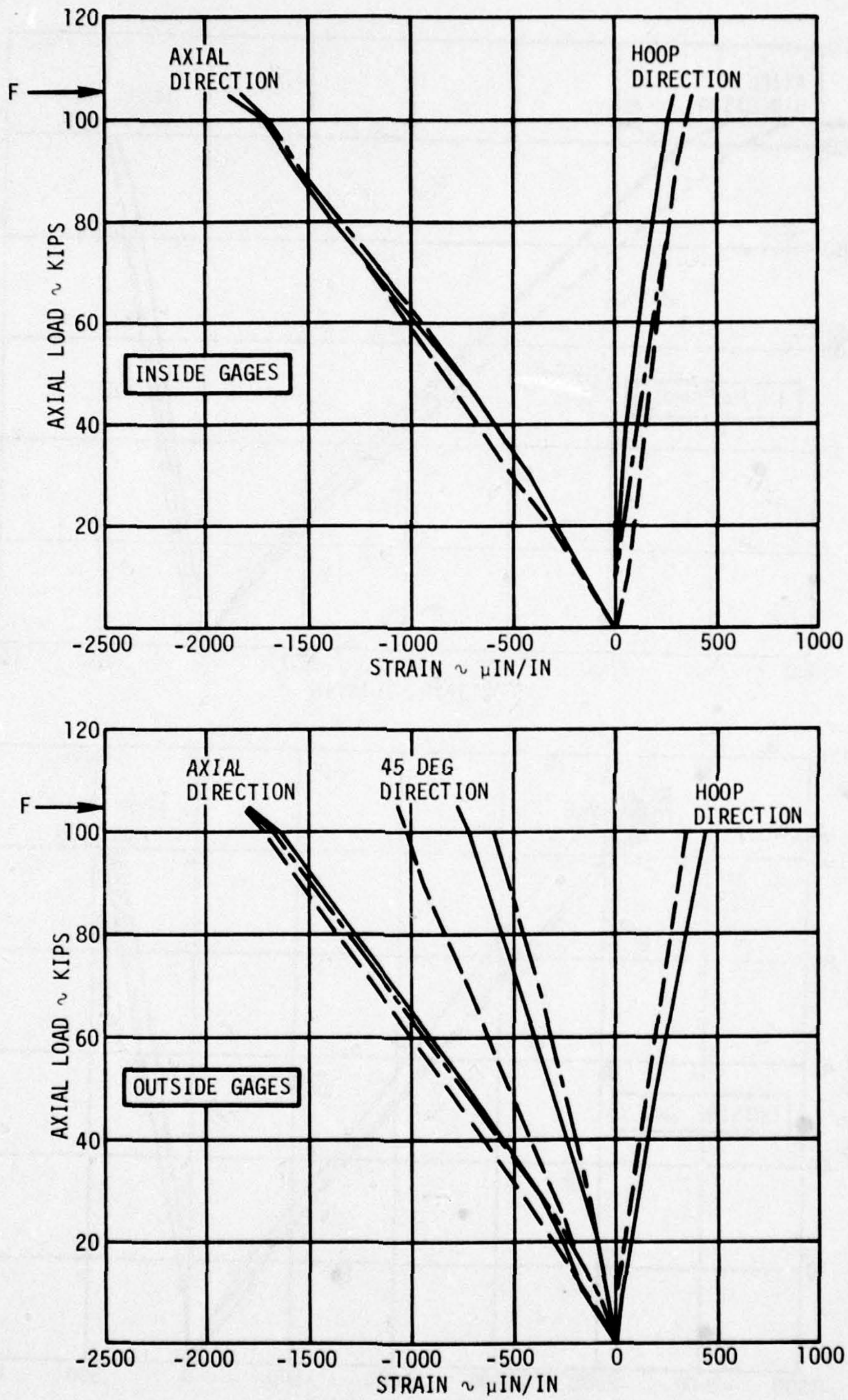


Figure 3.1-5. Cone 3 Axial Load Test - Section B-B
Strains versus Test Load

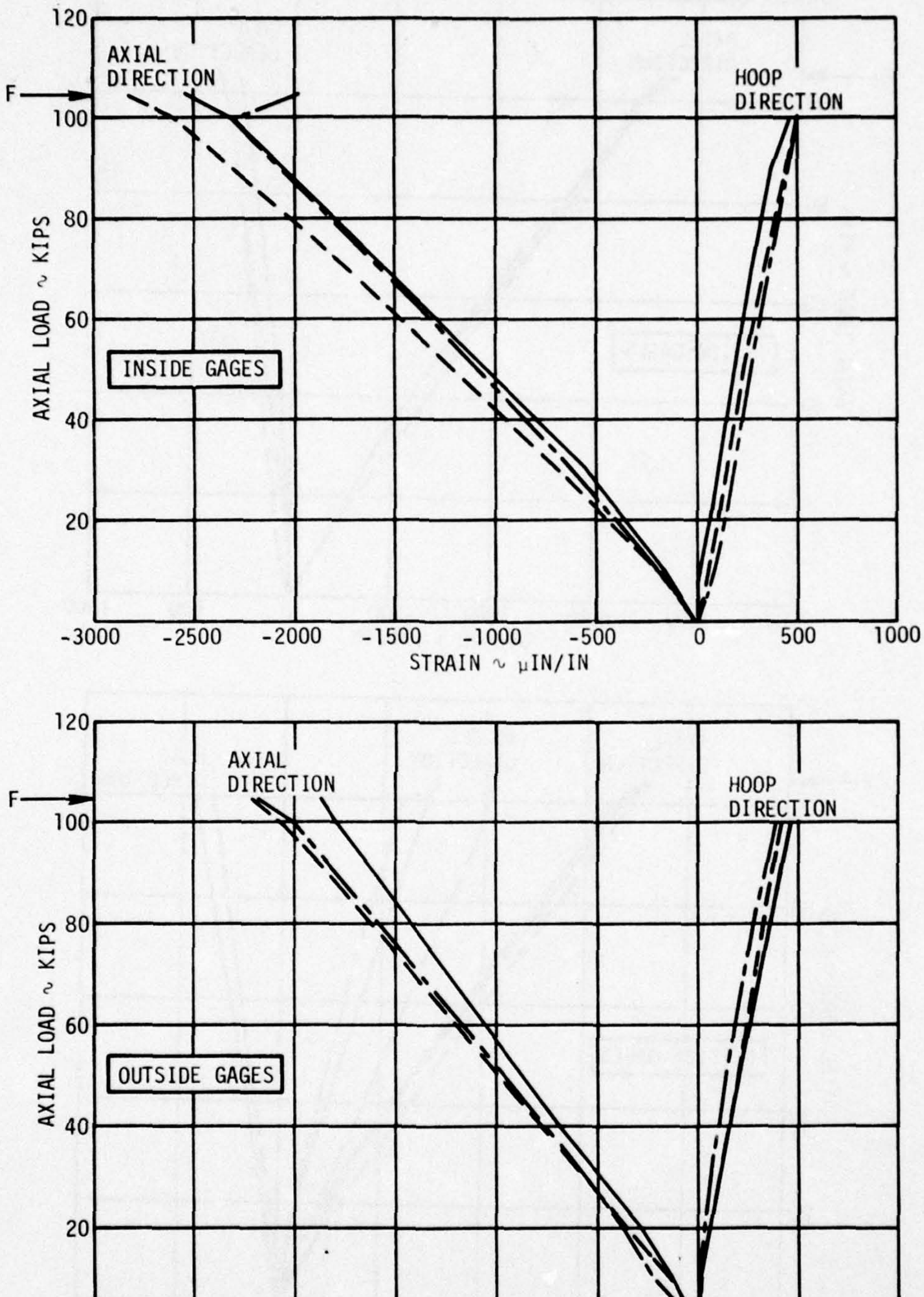


Figure 3.1-6. Cone 3 Axial Load Tsst - Section C-C
Strains versus Test Load

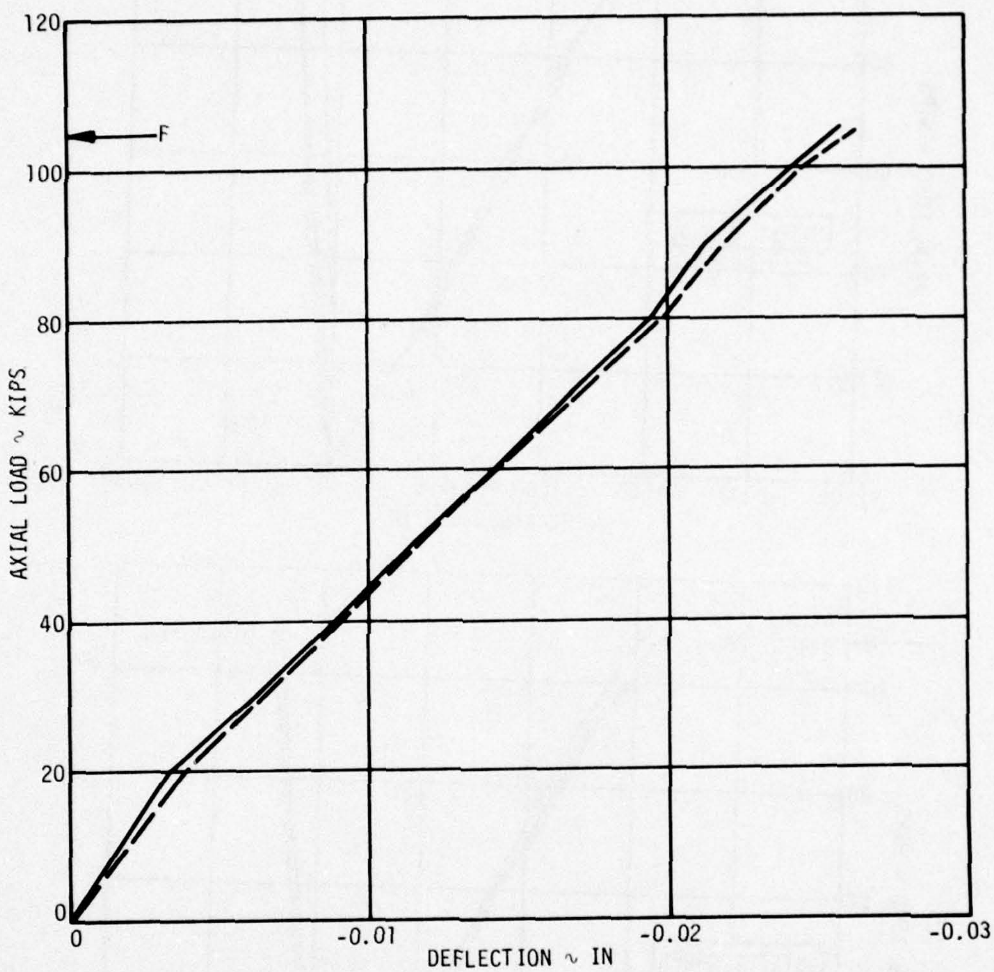
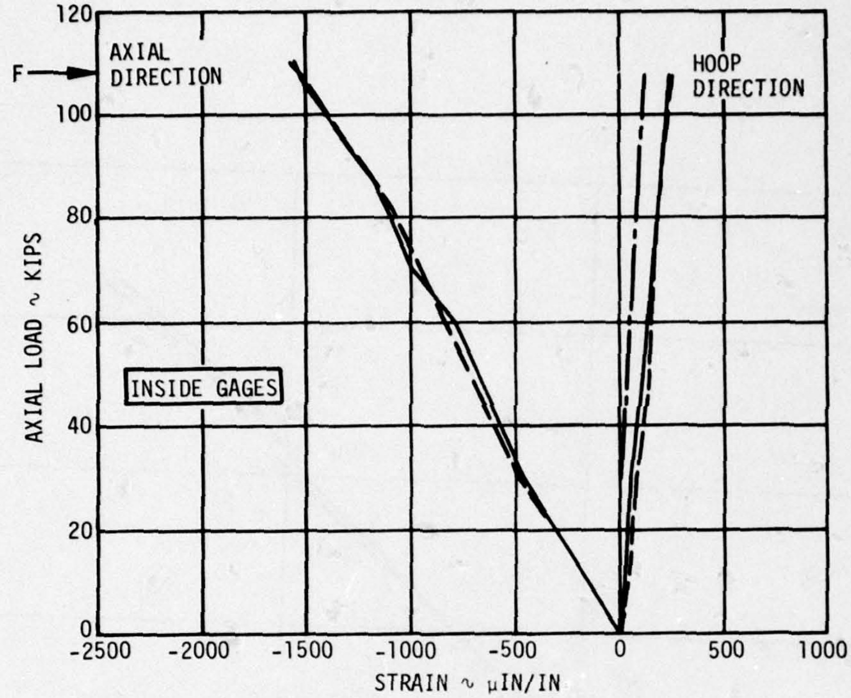


Figure 3.1-7. Cone 3 Axial Load Test -
Axial Deflection versus Load



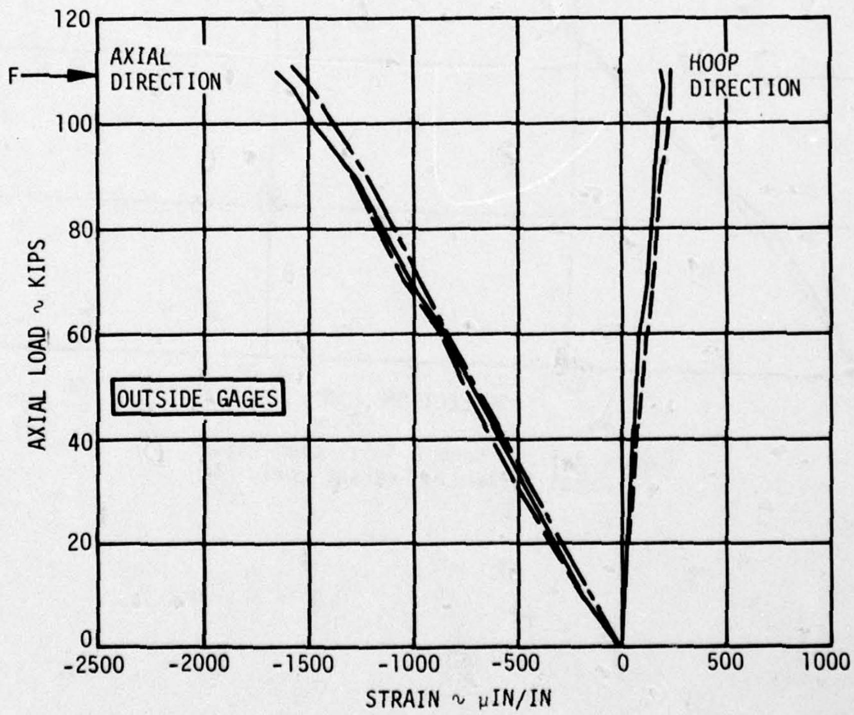


Figure 3.1-8. Cone 5 Axial Load Test - Section A-A
Strains versus Test Load

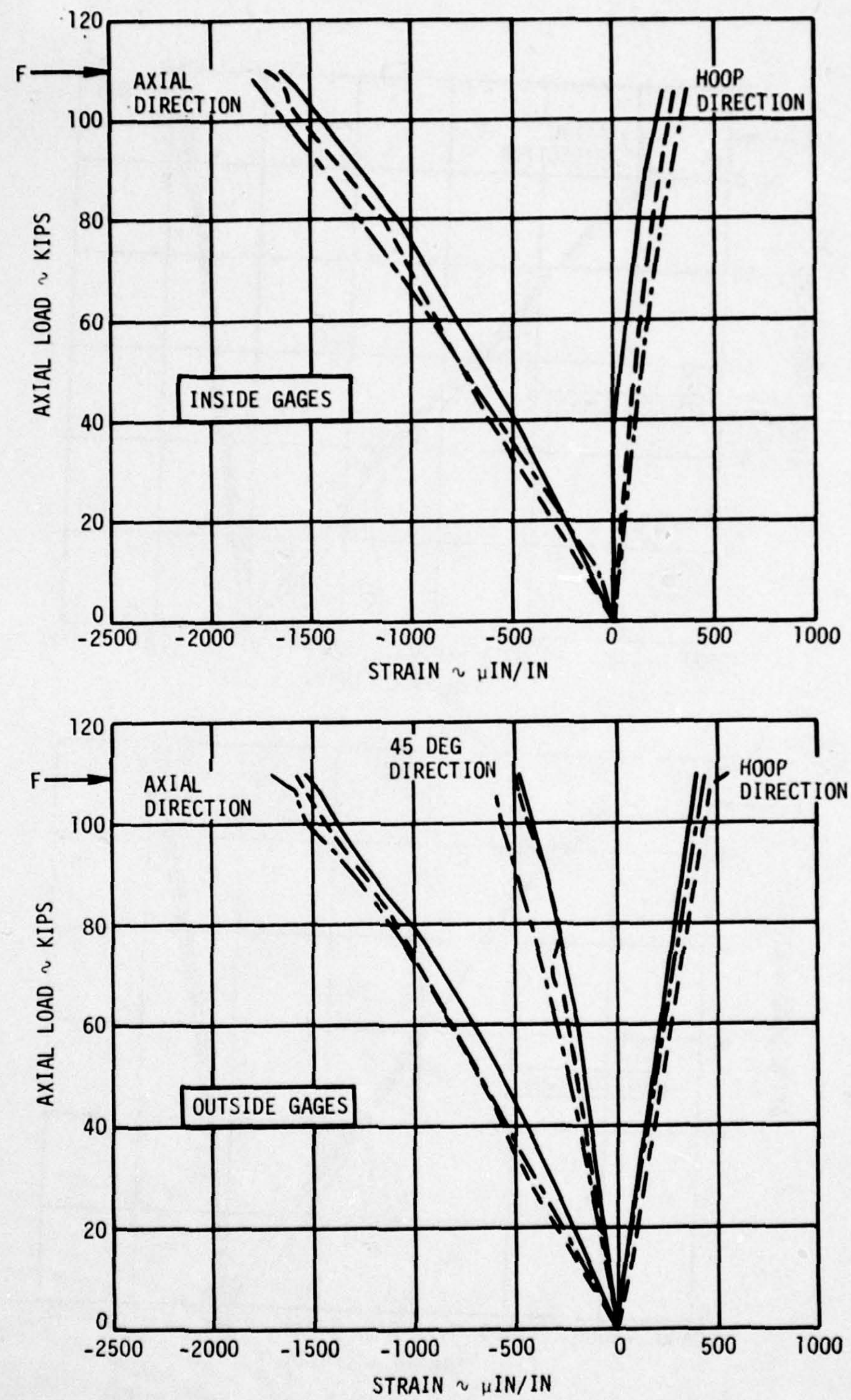
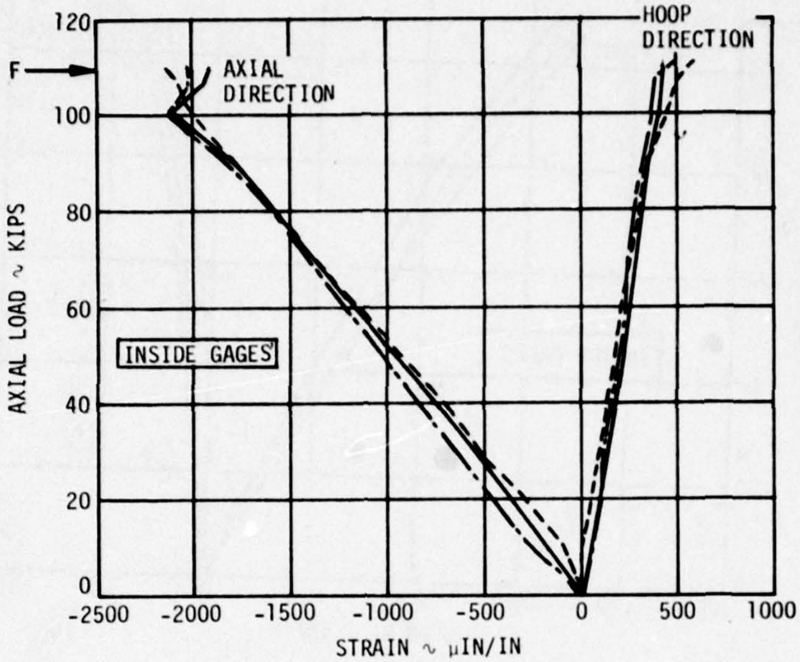


Figure 3.1-9. Cone 5 Axial Load Test - Section B-B
Strains versus Test Load



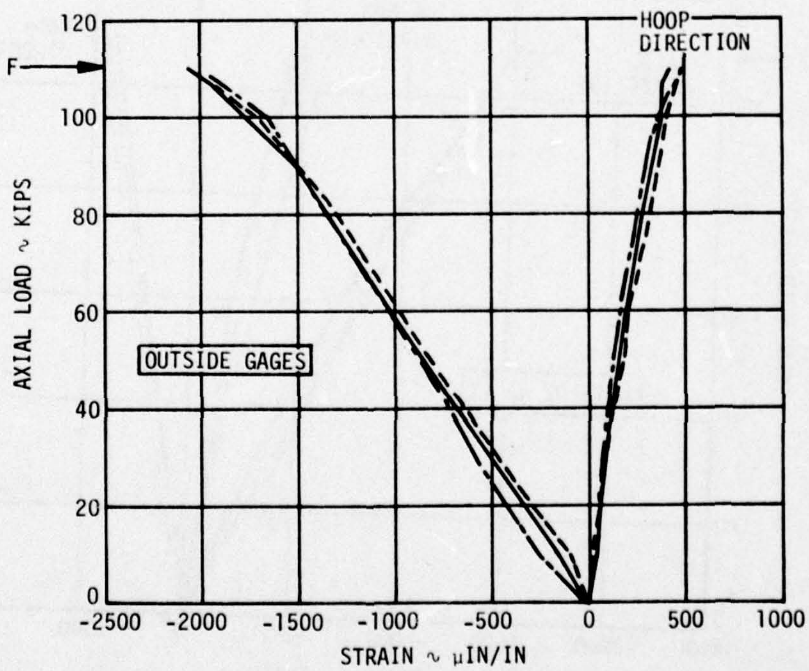


Figure 3.1-10. Cone 5 Axial Load Test - Section C-C Strains versus Test Load

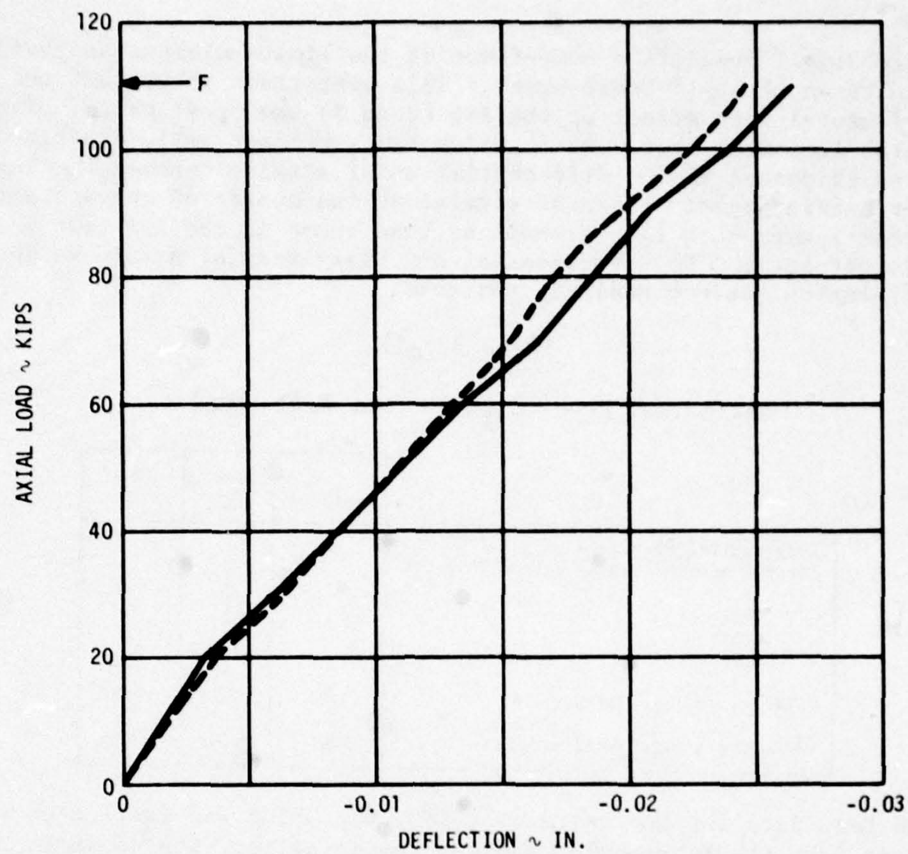


Figure 3.1-11. Cone 5 Axial Load Test - Axial Deflection versus Load

TABLE 3.1-I

Axial Load Test Results

Half-Scale Cone Fiber layup (27 ply) $[0_2/45/90_2/-45/0_2/45/90_2/-45/\underline{0}_3]_S$	Prediction Basis		Test Results		ASP Test Results (2 cones) (Reference 2)
	Laminate Theory	ASP Panel Tests	Cone No.3	Cone No.5	
Fiber volume (%)	60-62	59	54.4	54.9	52.0
Ultimate strength (kips)	100	100	105	110	116-120
Ultimate strain (μin/in)	-2500	-2680	-2830*	-2170*	-2540 to -2700*
Intial modulus (msi)	19.5	16.3	16.0**	16.1**	15.1-15.8**
Thickness (in)	0.124†	0.135	0.138	0.143	0.145
Line stiffness (10^6 lb/in)	2.42	2.20	2.21	2.30	2.19-2.29

*Largest measured compressive strain.

**Taken at 20,000 lb load, average of 18 longitudinal strain gages.

†Based on Fiberite's predicted ply thickness of 0.00460 inch.

Table 3.1-II presents a comparison of the finite element analysis and test results on the half-scale cones. This comparison shows that the maximum flexural edge effect at the top (cone 3) was predictable. Table 3.1-II also incicates that cone 5, which had a thicker wall, exhibited less flexure as evidenced by the differential axial strains between the inner and outer strain gages. Flexural strains at the center of cones 3 and 5 (0 to 7 percent) were much less pronounced than those of the ASP test series (13 to 14 percent). The hoop-to-axial and bias-to-axial strain ratios show good correlation between analysis and test.

TABLE 3.1-II

Analytical Predictions versus Test Results

	Analysis	Cone 3	Cone 5
Longitudinal flexure (Inside strain/outside strain-1) x 100%			
Top	20	21	9
Center	0	7	0
Bottom	-7	12	8
Hoop strain/axial strain	0.20	0.21	0.20
45 degree strain/axial strain	0.41	0.49	0.25

The test data for the extra cone (No. 6), which was fabricated using *deviations from the fabrication process specification*, are shown in Figures 3.1-12 through 3.1-14. This cone was instrumented with nine strain gages, and two axial deflections (diametrically opposite) were measured. Six of the nine strain gages were located near the critical small end. No data readings were taken above the 100,000 pound load level. The maximum strain at that load was -2230 μin/in.

The strains at section C-C and the deflection data both indicate that this cone was not as stiff as cones 3 and 5. The initial compressive modulus of elasticity of the laminate was calculated from test data to be 15.3×10^6 psi. The only indication in the strain data of an impending failure was one outside gage at section C-C (Figure 3.1-12) which experienced very little strain increase above 90,000 pound load, indicating essentially no increase of stress at that point as the load increased.

3.2 Combined Load Testing

3.2.1 Test Objectives

The objective of the combined load testing was to provide structural data for the evaluation of the strength and stiffness properties of a half-scale ultra-high modulus (GY70/934) graphite/epoxy cone frustum under a combined loading simulating the critical in-flight design condition for a high performance BMD interceptor structure. The test data obtained by these tests augments the results of axial load testing at Martin Marietta's Denver Division.

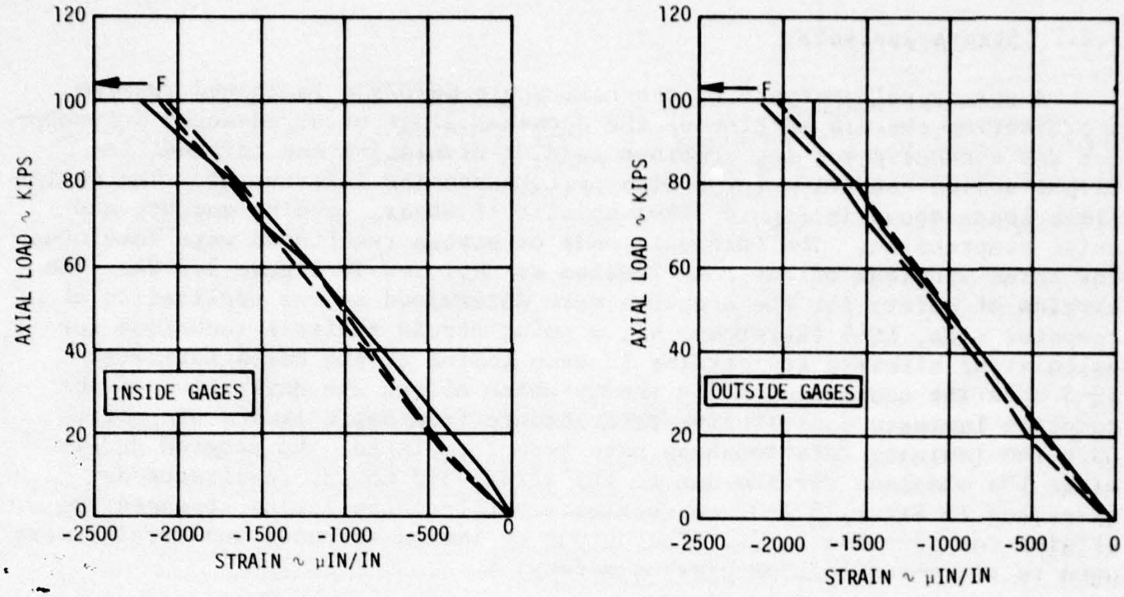


Figure 3.1-12. Cone 6 Axial Load Test - Section C-C Strains versus Test Load

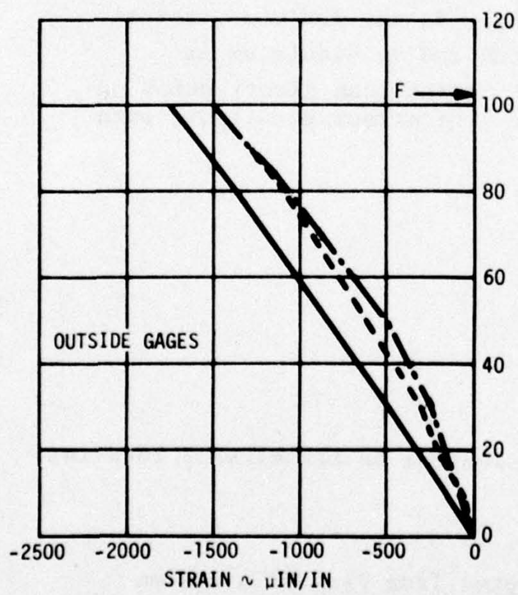


Figure 3.1-13. Cone 6 Axial Load Test - Section B-B Strains versus Test Load

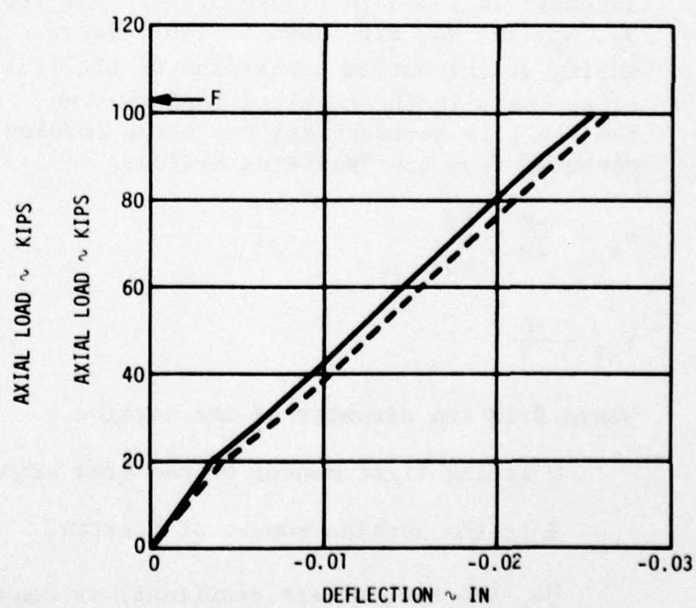


Figure 3.1-14. Cone 6 Axial Load Test - Axial Deflection versus Test Load

3.2.2 Stress Analysis

A structural analysis of the half-scale GY70/934 laminated frustum representing the aft section of the terminal stage of an advanced interceptor was conducted for the combined loading simulating the critical inflight design condition for a high performance BMD interceptor. The design limit loads shown in Figure 3.2-1 consist of shear, bending moment, and axial compression. The internal loads or stress resultants were developed for three sections of the cone frustum as depicted in Figure 3.2-2a. The margins of safety for the sections were determined by the application of a computer code, SQ-5 (Reference 4), a point stress analysis technique for calculating stresses and strains in each lamina of the cured laminate. SQ-5 uses the usual lamination theory which allows the derivation of the complete laminate constitutive relationship from basic lamina properties. Once the laminate relationships have been formulated, the program determines the midplane strains due to the stress and moment resultants as described in Figure 3.2-3, and ultimately calculates lamina stresses and strains for in-plane loads. The output of lamina stresses and strains were used to calculate test margins of safety.

At each of the three sections, three circumferential locations were selected for stress and strain determinations as shown in Figure 3.2-2b. The calculations for the stress resultants are based on the design loads of Figure 3.2-1 and the geometry of the cone frustum which is depicted in Figure 3.2-4. The aluminum rings are bonded to the shell to serve as loading and mounting fixtures for the combined load test. The bonded assembly is shown in Figure 3.2-5. The input data for stress resultants N_x, N_y, and N_{xy} are shown in Table 3.2-I. P_{max} is the maximum pressure acting at the bottom centerline of the frustum and is simulated by strap loads in the combined load testing. A cosine load distribution on the shell is assumed from the strap loading. The stress resultants were computed from the following methods:

$$N_x = \frac{-P}{\pi D} \pm \frac{4M}{\pi D^2}$$

$$N_{xy} = \frac{VQ}{I}$$

where D is the diameter of the section

Q is the first moment of the area with respect to the element location

I is the section moment of inertia.

N_y, the hoop stress resultant, is computed from P_{max} of a cosine pressure distribution. A rigid ring assumption is made in the computation. The unidirectional lamina material properties for GY70/934 required for input data are listed in Table 3.2-II. The laminate layup sequence is shown in Figure 3.2-4. A lamina thickness of 0.005 inch was assumed.

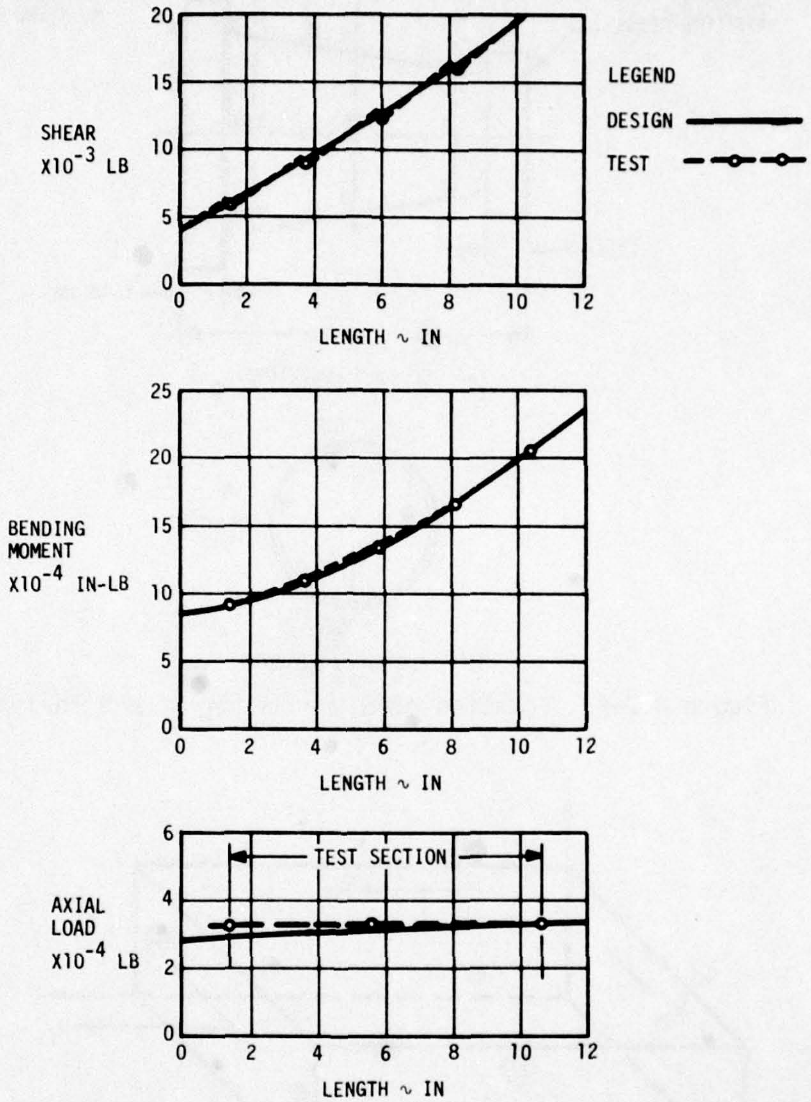


Figure 3.2-1. Limit Design and Test Loads - Combined Load Condition

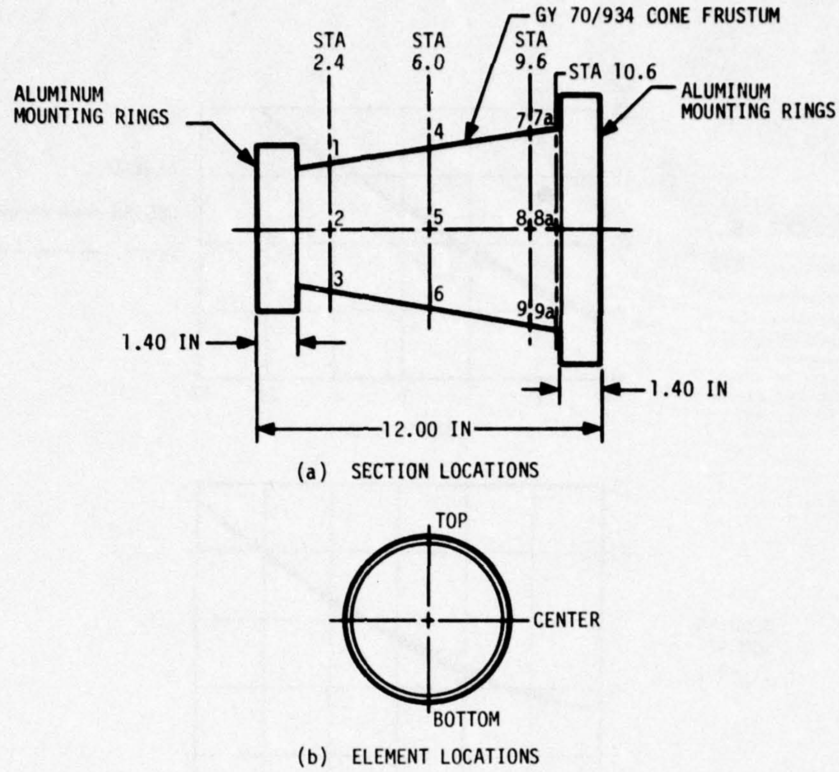


Figure 3.2-2. Location of Elements for Stress Analysis

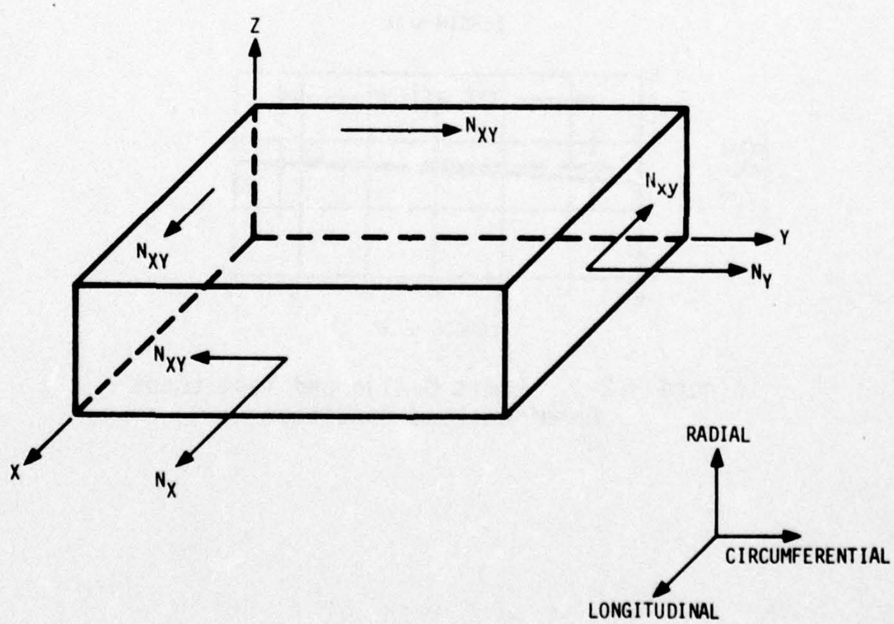
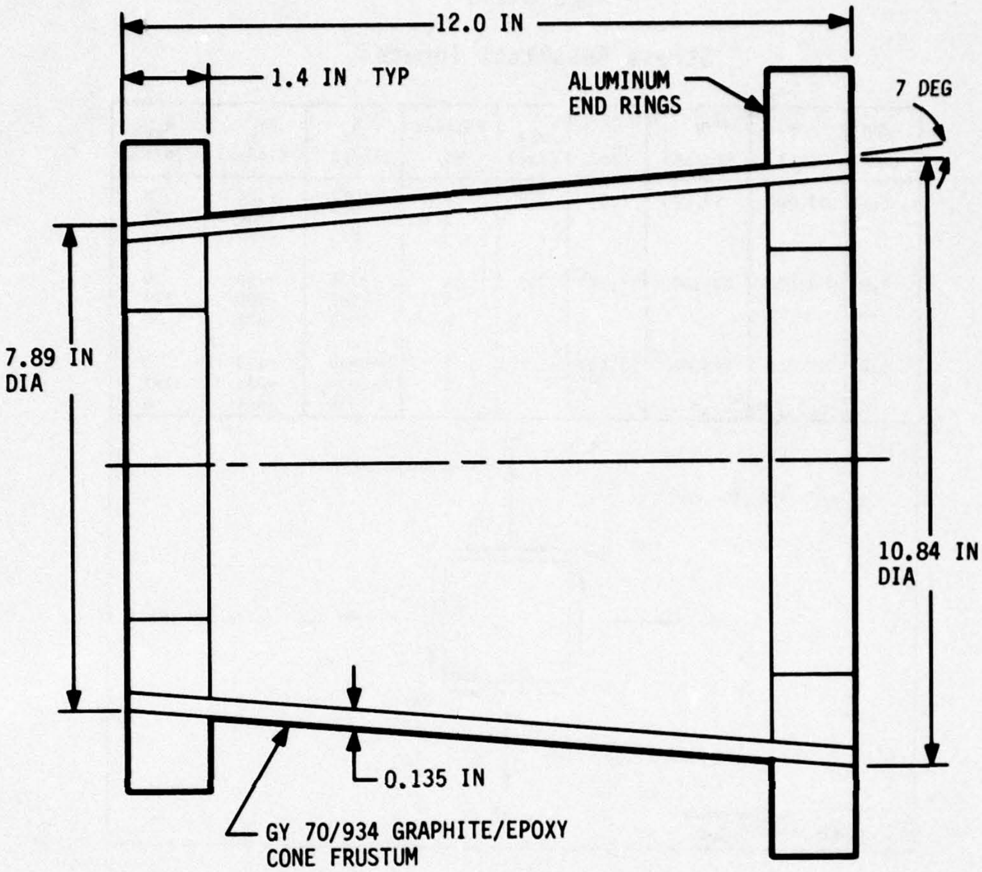


Figure 3.2-3. Stress Resultants and Their Orientation



$[0_2/45/90_2/-45/0_2/45/90_2/-45/\underline{0}_3]_S$ PLY LAMINA LAYUP (27 PLIES)

Figure 3.2-4. Geometry of Cone Frustum

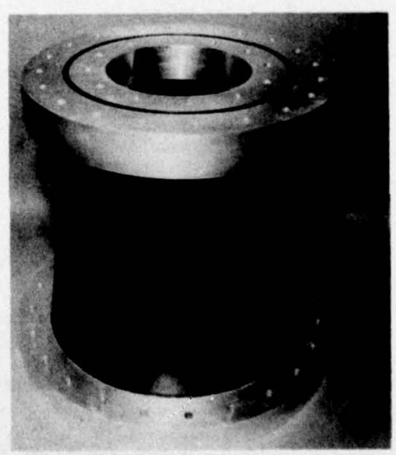


Figure 3.2-5. Aluminum End Rings Bonded to Conical Frustum

TABLE 3.2-I

Stress Resultant Inputs

STA (in)	P (lb)	M (in/lb)	V (lb)	P_{max} (psi)	Element No.	N_x (lb/in)	N_y (lb/in)	N_{xy} (lb/in)
2.4	33,000	99,000	7,200	248	1	-3073	-128	0
					2	-1297	-800	472
					3	479	-384	0
6.0	33,000	135,000	13,500	239	4	-3238	-144	0
					5	-1109	-900	974
					6	1020	-432	0
9.6	33,000	190,000	18,600	230	7	-3436	-148	0
					8	-1039	-925	1165
					9	1358	-444	0

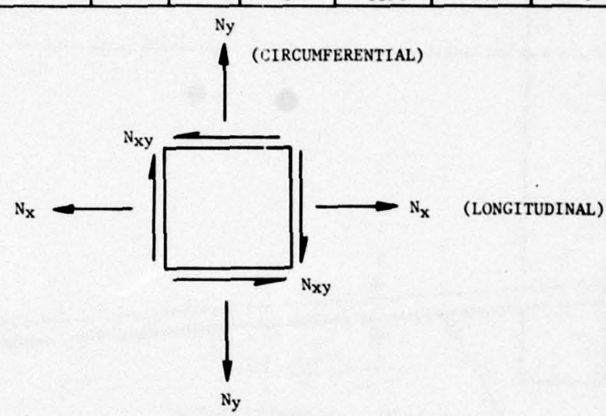


TABLE 3.2-II

Unidirectional Lamina Material Properties GY70/934

Property		Value
Fiber volume	---	60%
Longitudinal modulus	E_{11}	43.0 msi (T) 40.5 msi (C)
Transverse modulus	E_{22}	0.84 msi
Shear modulus	G_{12}	0.80 msi
Poisson's ratio	ν_{12}	0.12
Longitudinal strength	σ_{11}	2100 μin/in (T) 2500 μin/in (C)
Transverse strain	σ_{22}	3300 μin/in
Shear strain	γ_{12}	10,900 μin/in
Longitudinal thermal coefficient	α_1	-0.65×16^{-6} in/in/°F
Transverse thermal coefficient	α_2	16.5×10^{-6} in/in/°F

T denotes tension
C denotes compression

The output of this analysis includes the elastic properties of the laminate, the stress and strain components and margins of safety for each lamina of input elements, and an interaction diagram to describe a failure envelope. The critical strains and minimum margin of safety are listed in Table 3.2-III. The locations of the elements are identified in Figure 3.2-2. Stations 2.4, 6.0, and 9.6 correspond to the locations of strain gages installed for the test cones. Elements 7a, 8a, and 9a represent the locations of maximum strains. For a given element, the critical ply angle implies that all layers of that angle have the critical strains shown. The critical strains are all ε_{11} or in the direction of the fibers for each element. The other two strain components, ε_{22} and γ_{12}, strain normal to the fibers and shear strain respectively, are not critical. In the vicinity of the aluminum rings, a discontinuity stress factor is applied to the stresses and strains computed from SQ-5. Tension and compression factors of 1.80 and 1.27 respectively, obtained from Reference 1 are used in the computation of effective margins of safety. Elements 4, 5, and 6 which are located at midsection of the shell are not affected by the factors. Therefore, the minimum margin of safety for the GY70/934 laminated frustum in the static test configuration is 29 percent over the design loads.

TABLE 3.2-III

Critical Strains and Margins

Element No.	Critical Ply Angle	Strain, ε_{11} (μin/in)	Minimum Margin of Safety*	Effective Margin of Safety
1	0	-1091	1.29	0.80
2	-45	- 806	2.10	1.44
3	0	+ 197	9.65	4.92
4	0	-1149	1.17	1.17
5	-45	-1288	0.94	0.94
6	0	+ 394	4.33	4.33
7	0	-1220	1.05	0.61
8	-45	-1469	0.70	0.34
9	0	516	3.07	1.26
7a	0	-1257	0.99	0.57
8a	-45	-1528	0.64	0.29
9a	0	570	2.68	1.11

*Margin of safety = $\frac{\text{allowable strain}}{\text{limit strain}} - 1$

The 1.4 inch thick 6061-T6 aluminum rings designed to support and transfer test loads to the shell are bonded to the shell with room temperature cure adhesive EA9309, a HYSOL product. Extensive adhesive strength testing and evaluations were conducted under AMMRC contract DAAG46-75-C-0097. The results (Reference 1) showed that Hysol adhesive EA9309 had good shear strength and elongation property as a bonding agent between graphite-/epoxy laminate and aluminum alloy for room temperature applications. It has an average shear strength of 4750 psi and a peel strength of 39 psi.

The bond line for the aft aluminum rings has a maximum average shear stress resulting from the design limit loads (P=-33,000 pounds and M=240,000 inch-pounds) of 1305 psi as shown in Figure 3.2-6. The margin of safety is determined as follows:

$$\text{Margin of safety} = \frac{4750}{1305} - 1 = 2.6$$

This ample margin would allow 260 percent over the design limit loading before bond line failure.

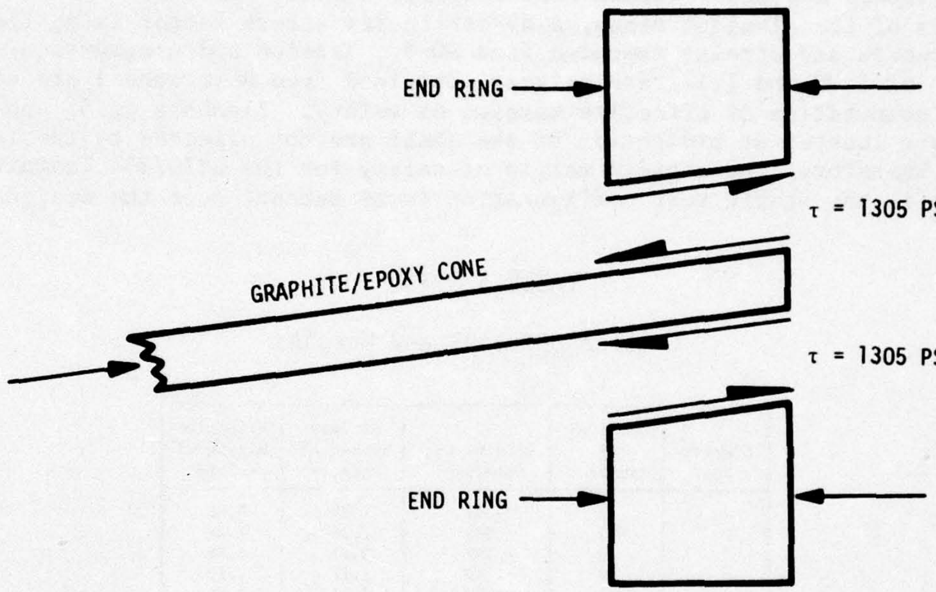


Figure 3.2-6. Shear in Aft Ring Bondline

3.2.3 Test Procedure

Three graphite/epoxy (GY70/934) test frusta, cones 1,2, and 4, fabricated by Martin Marietta's Denver Division were tested under combined static loads at the Environmental Test Laboratory of Martin Marietta's Orlando Division. The frusta were fabricated per Martin Marietta drawing No. SK27292 and the manufacturing process plan (Appendix A). The conical frustum is 12 inches long with end diameters of 10.84 inches and 7.89 inches. The nominal shell thickness is 0.135 inch.

Inner and outer rings of 6061-T6 aluminum alloy were bonded to the shell at each end to provide attachments for load applications and reaction (Figure 3.2-5). A photograph of the test setup is shown in Figure 3.2-7. The test specimen was bolted at the large end to the test fixture and at the small end to a loading fixture. Two hydraulic jacks aligned parallel to the shell axis provided axial compression and end moment to the small

end of the test specimen through the loading fixture and a third jack provided a transverse shear load to the specimen through the same fixture. A fourth jack, connecting a whiffle tree arrangement which is bolted to loading straps wrapped around the conical shell, provided the distributed shear loading to the specimen simulating the external pressure loading.

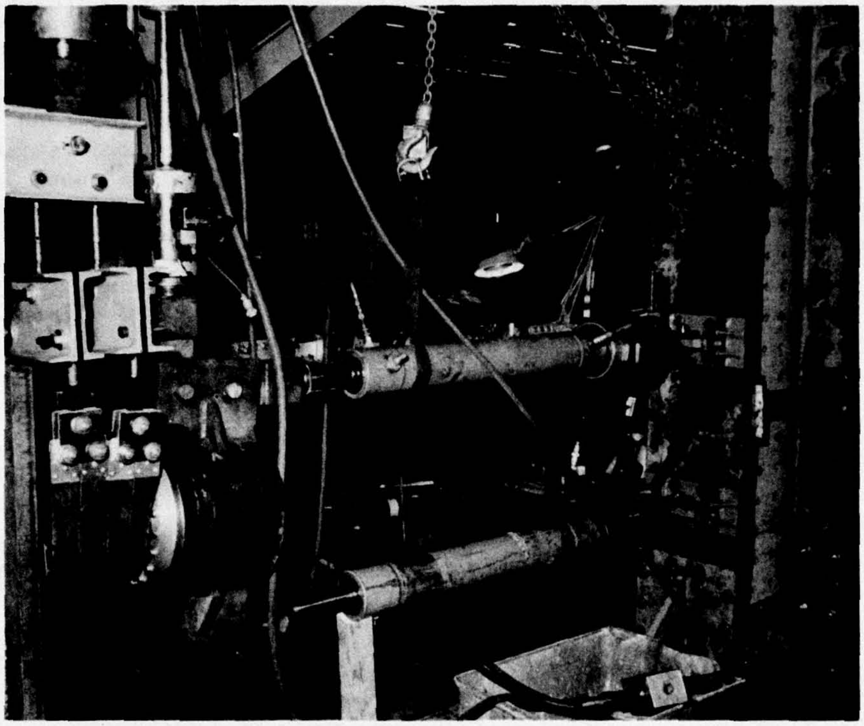


Figure 3.2-7. Combined Load Test Setup

Strain measurements were taken during the tests from the 30 axial type strain gages (FAE 25S12S6) and 3 rosette type strain gages (FAER 25B12S6) installed on the test specimen as shown in Figure 3.2-8.

Four direct current displacement transducers (DCDT) were located at the small end of the specimen and at the test fixtures to measure the net end deflection of the test specimen. The locations of the DCDT's and the test setup are given in Figure 3.2-9.

The loads were applied to the test cone through the four hydraulic jacks incrementally until failure occurred. The detailed test procedure and loading sequence are given in Appendix B.

3.2.4 Test Results and Data Analysis

For the three combined load tests, strain gage and DCDT deflection readings were taken at each loading increment. All readings after being zero adjusted were plotted against percent of design limit load (DLL).

Strains were measured in micro-inch per inch and displacements in inches. The test data for test 1 (cone 1) are shown in Figures 3.2-10 through 3.2-17; for test 2 (cone 2) in Figures 3.2-18 through 3.2-25; and for test 3 (cone 4) in Figures 3.2-26 through 3.2-33. The failure load for each of the test cones is given in the plotted data. The first cone failed at 120 percent of DLL; the second cone at 130 percent of DLL; and the third test cone at 140 percent of DLL. The spread of the failure loads represents a variation of 7.7 percent from the mean value. This variation is considered acceptable since the allowable unidirectional laminate strength variation is 10 percent as specified in the material specification (Reference 5). All failures of the test cones occurred at the large end of the cone next to the aluminum rings, where the graphite/epoxy shell fractured completely around the circumference. The typical fractured test cone is shown in Figure 3.2-34. In this photograph, the bottom (tension) side of the cone is facing forward and is designated 180 degrees.

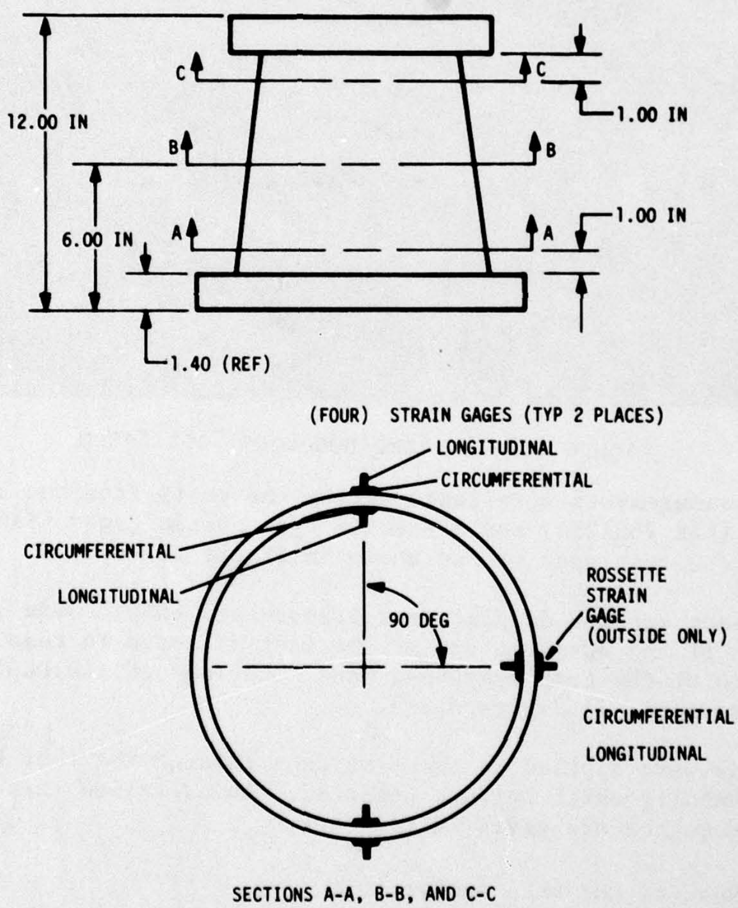


Figure 3.2-8. Strain Gage Locations

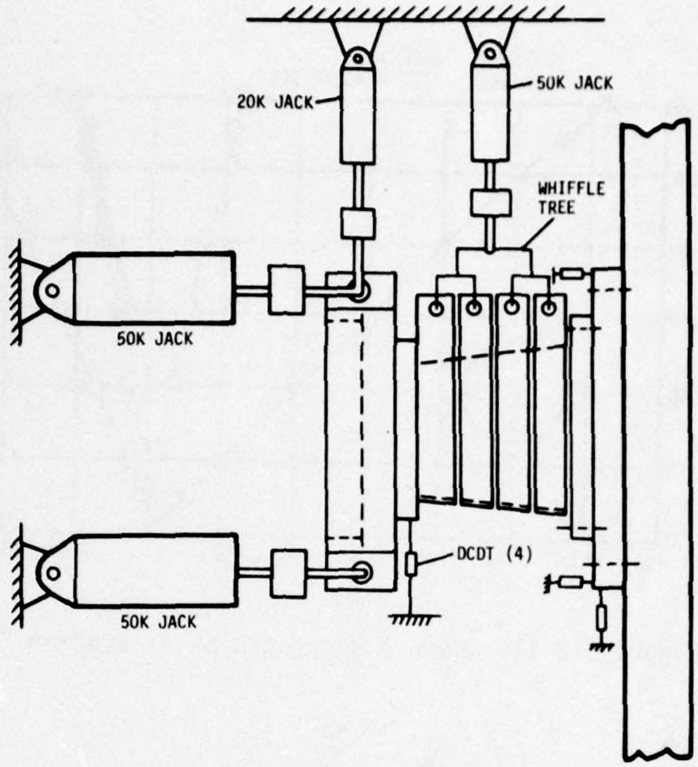


Figure 3.2-9. Locations of Delfection Gages and Combined Load Test Setup

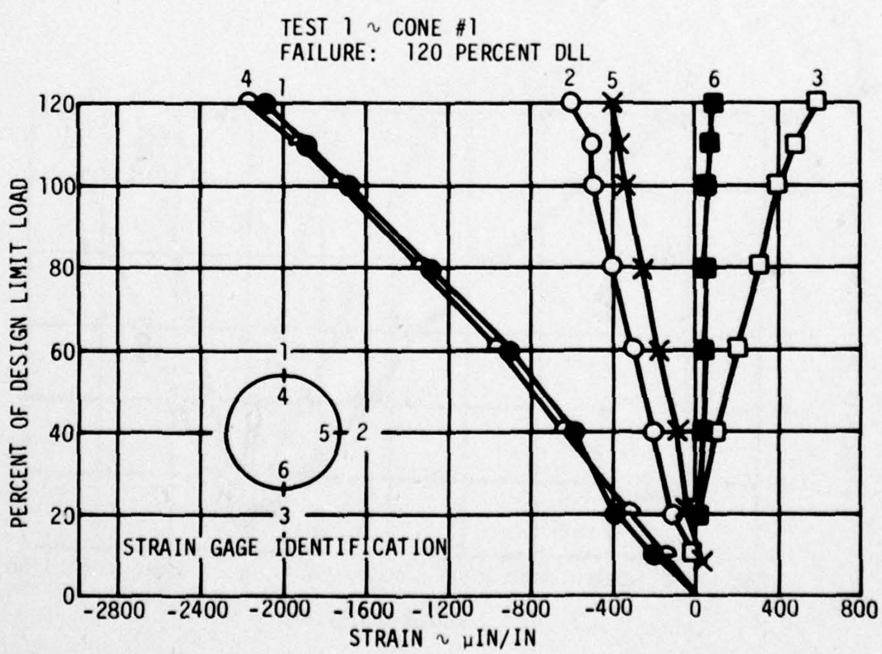


Figure 3.2-10. Cone 1 Longitudinal Strains at Station 2.40

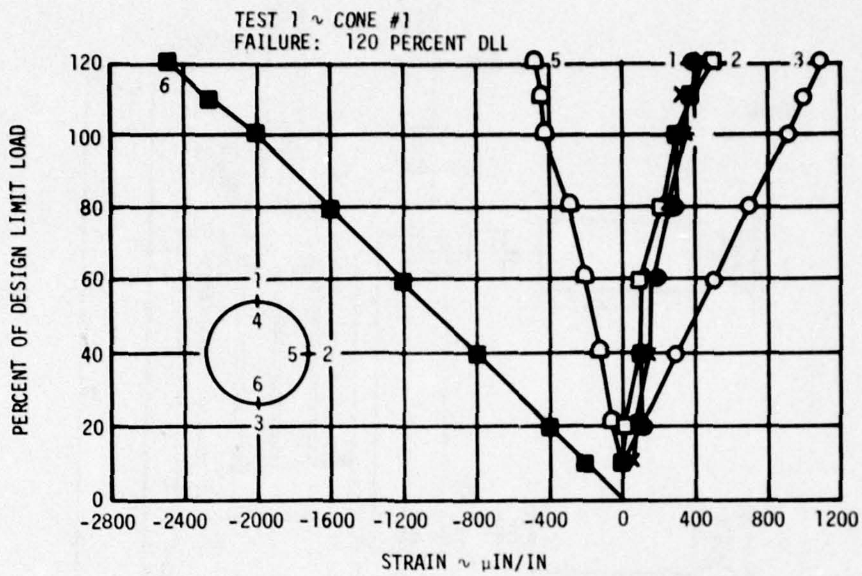


Figure 3.2-11. Cone 1 Hoop Strains at Station 2.40

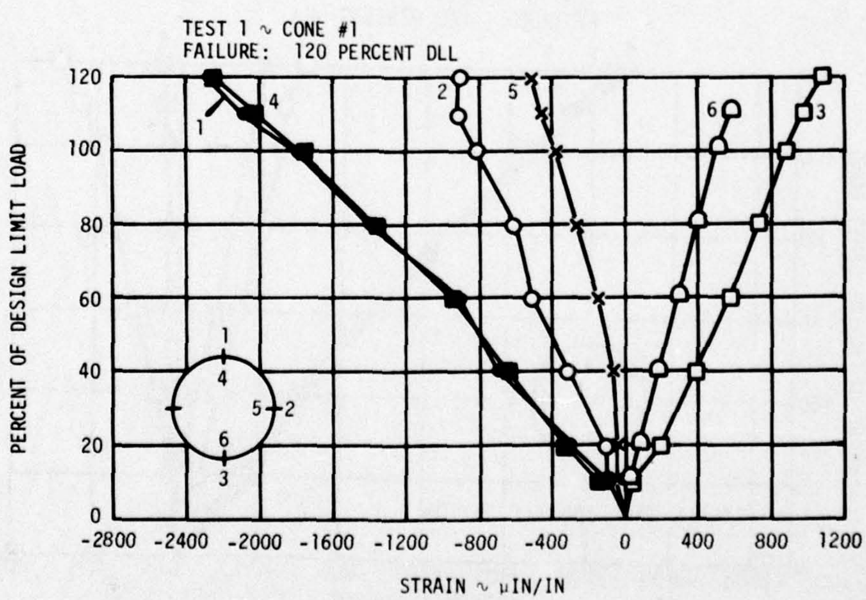


Figure 3.2-12. Cone 1 Longitudinal Strains at Station 6.0

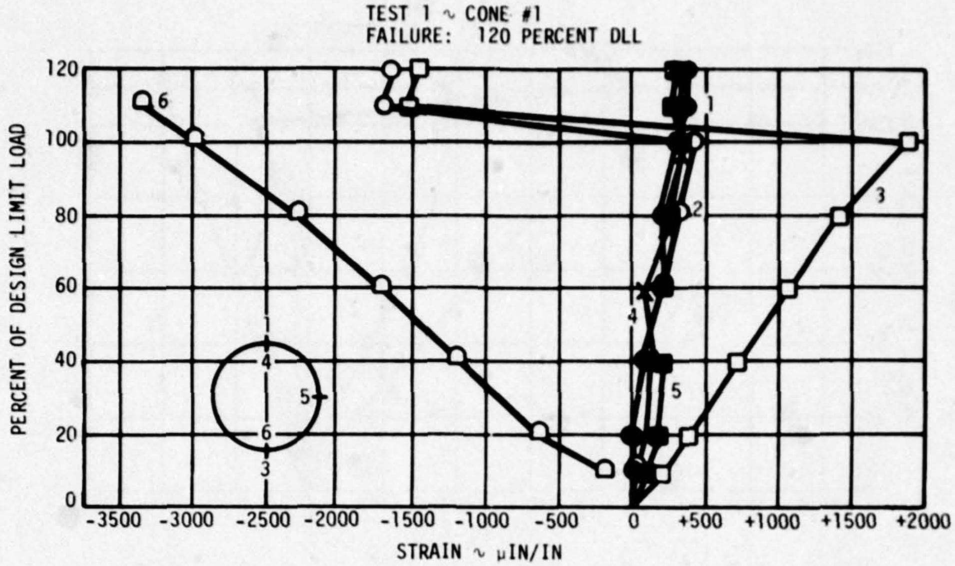


Figure 3.2-13. Cone 1 Hoop Strains at Station 6.0

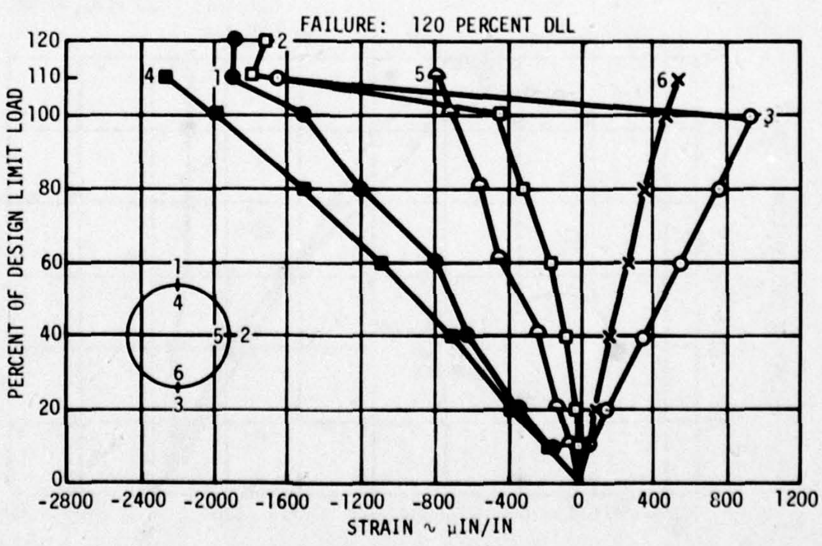


Figure 3.2-14. Cone 1 Longitudinal Strains at Station 9.60

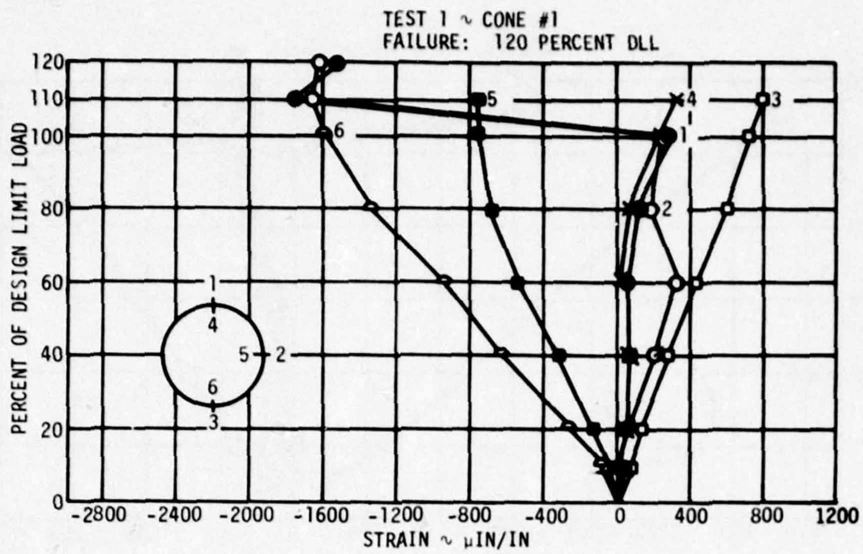


Figure 3.2-15. Cone 1 Hoop Strains at Station 9.60

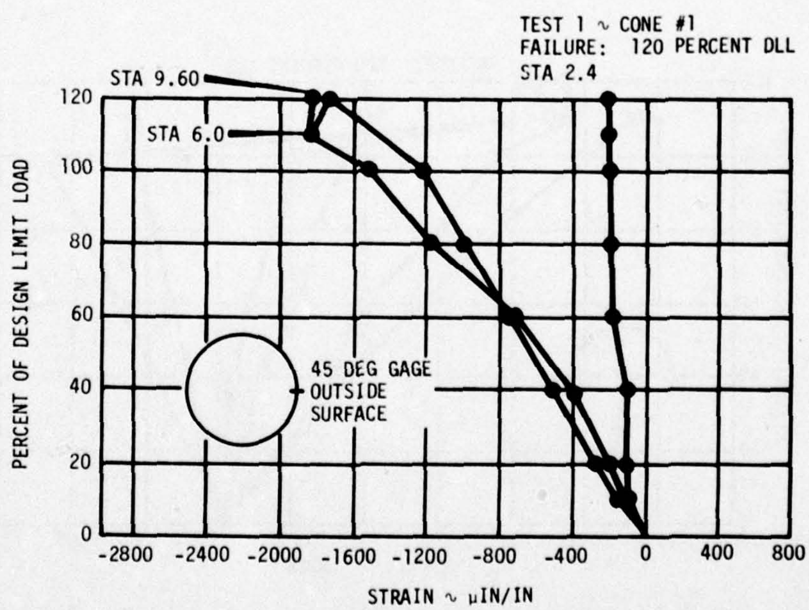


Figure 3.2-16. Cone 1 45 Degree Strains

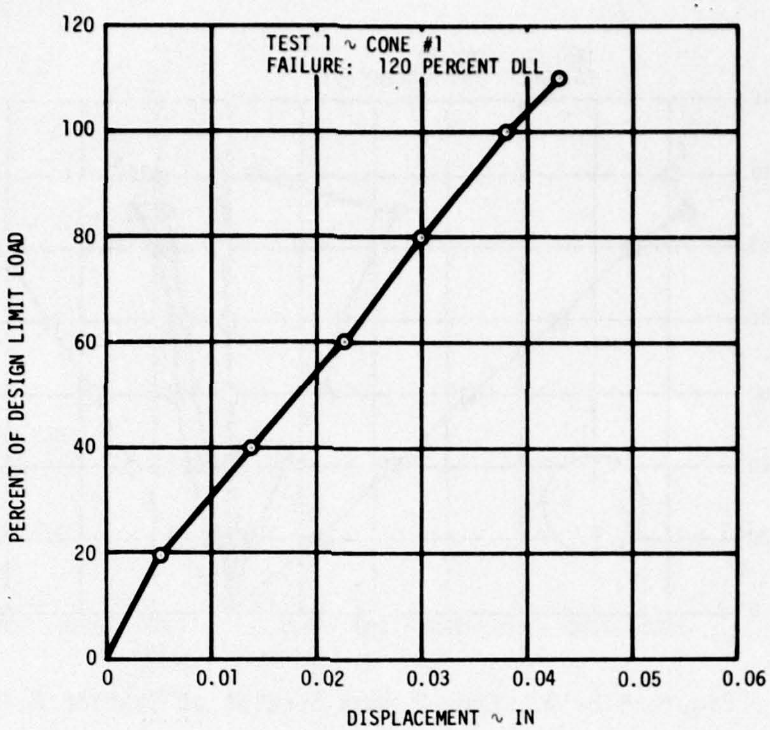


Figure 3.2-17. Cone 1 Lateral Displacement at Forward End of Frustum

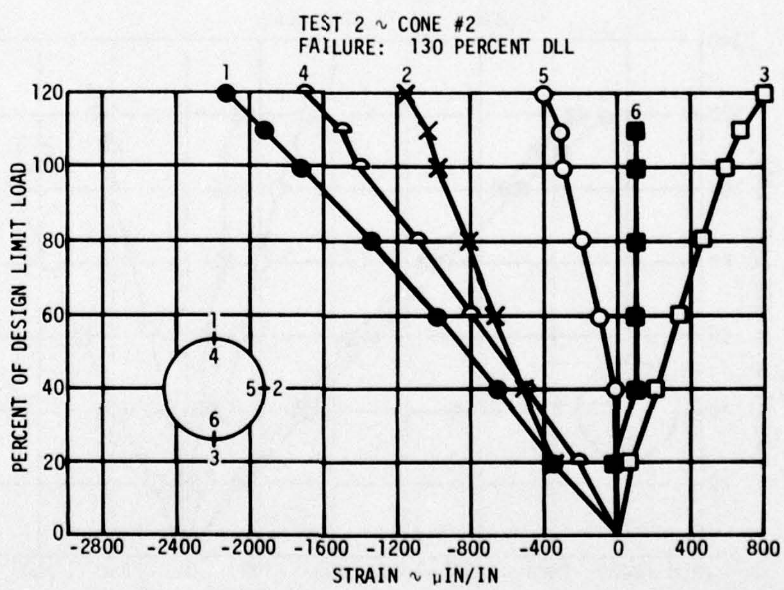


Figure 3.2-18. Cone 2 Longitudinal Strains at Station 2.40

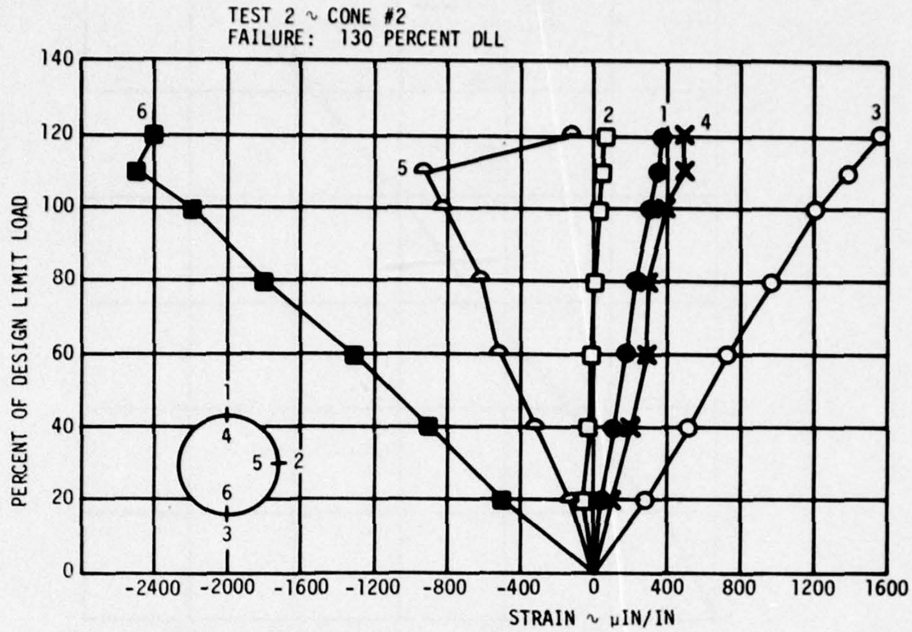


Figure 3.2-19. Cone 2 Hoop Strains at Station 2.40

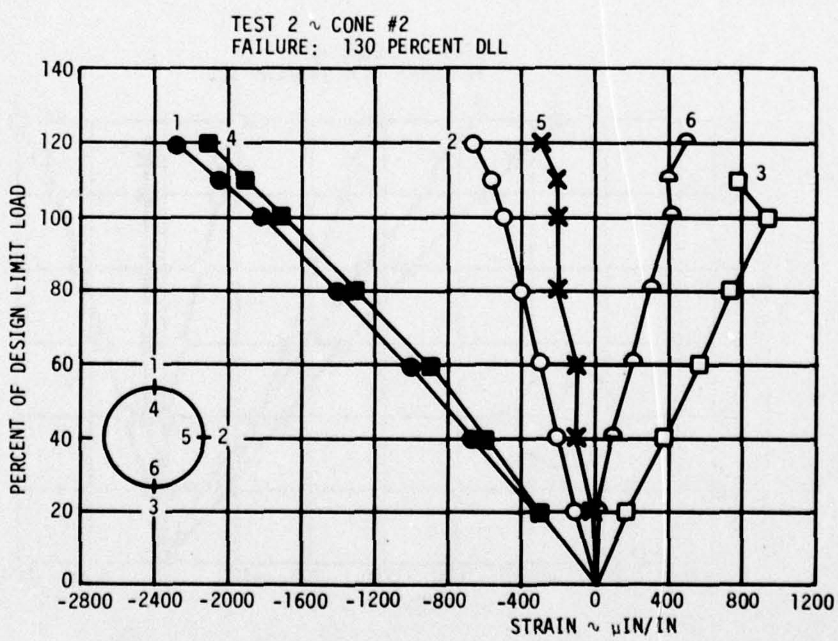


Figure 3.2-20. Cone 2 Longitudinal Strains at Station 2.40

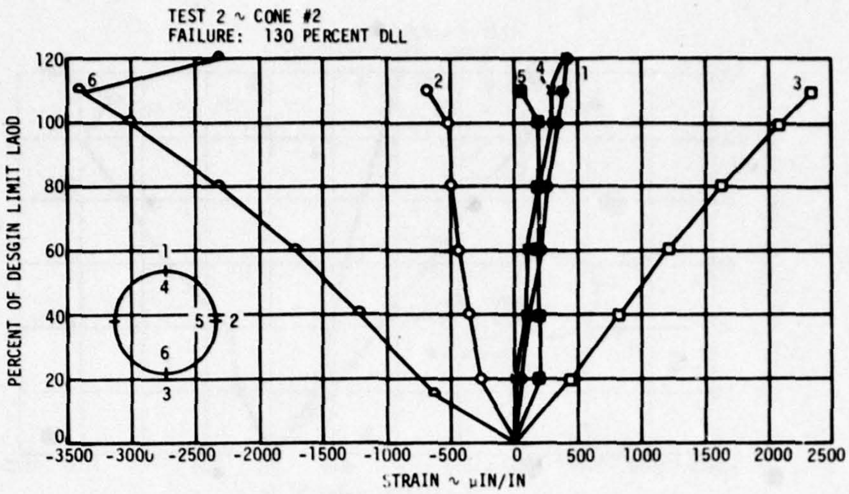


Figure 3.2-21. Cone 2 Hoop Strains at Station 6.0

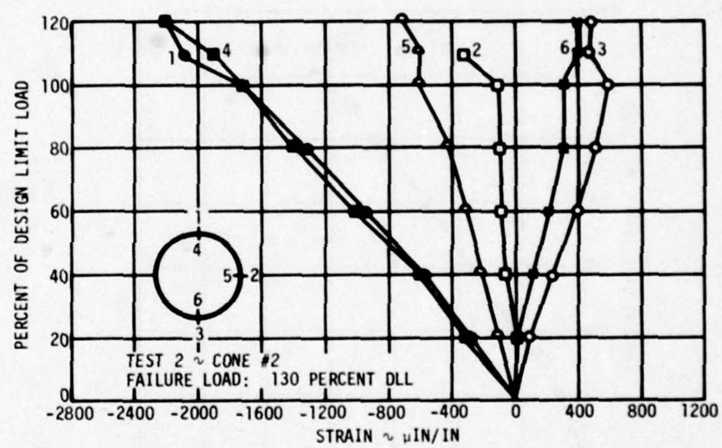


Figure 3.2-22. Cone 2 Longitudinal Strains at Station 9.60

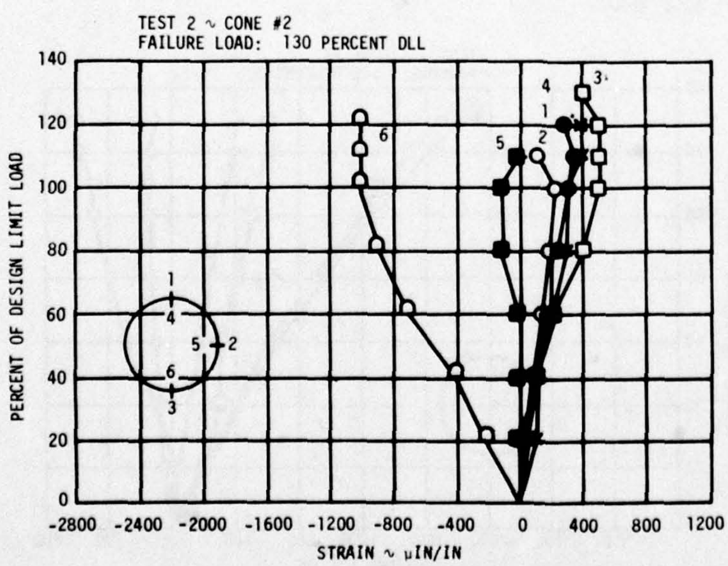


Figure 3.2-23. Cone 2 Hoop Strains at Station 9.60

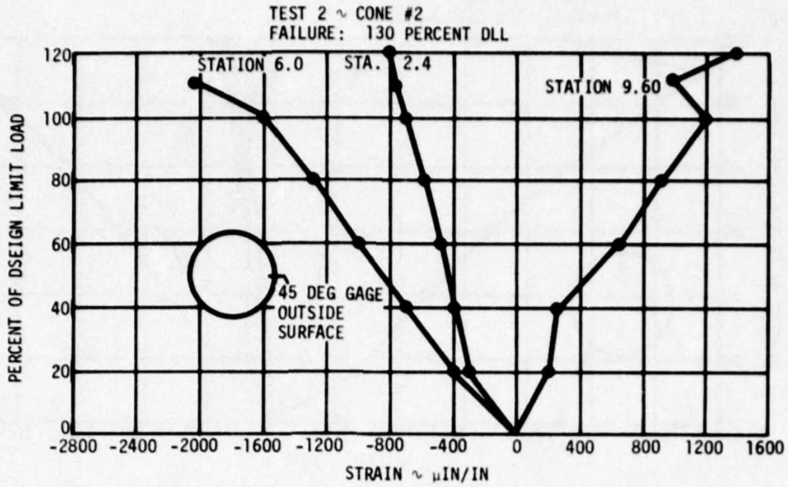


Figure 3.2-24. Cone 2 45 Degree Strains

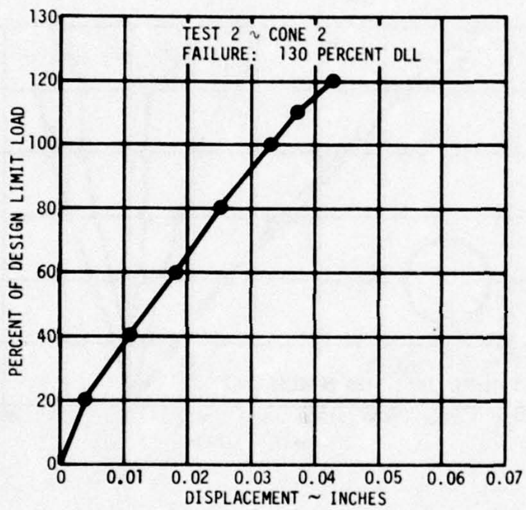


Figure 3.2-25. Cone 2 Lateral Displacement at Forward End

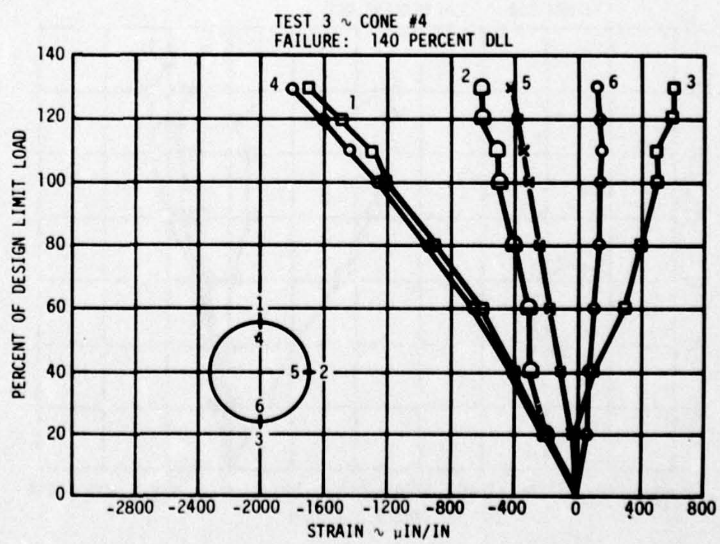


Figure 3.2-26. Cone 4 Longitudinal Strains at Station 2.40

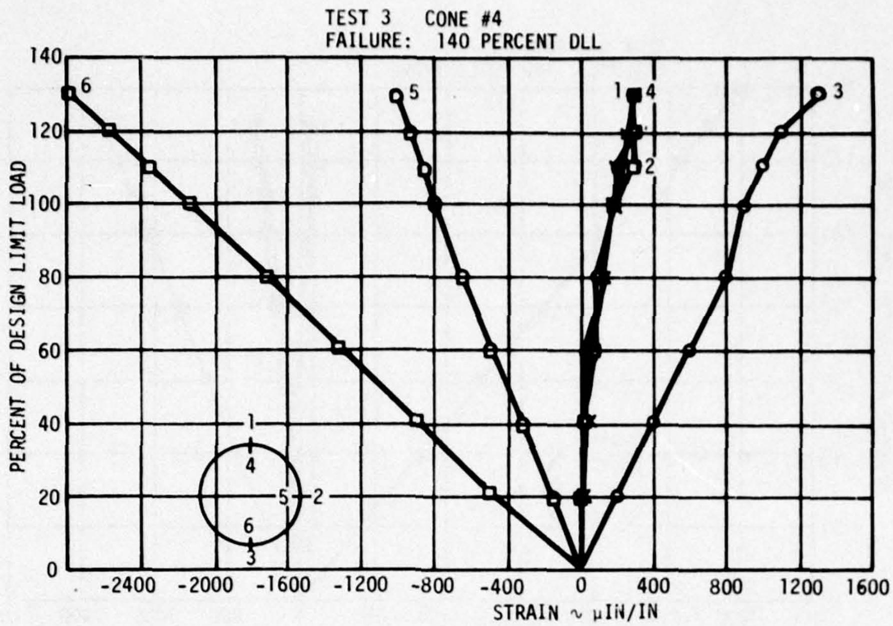


Figure 3.2-27. Cone 4 Hoop Strains at Station 2.40

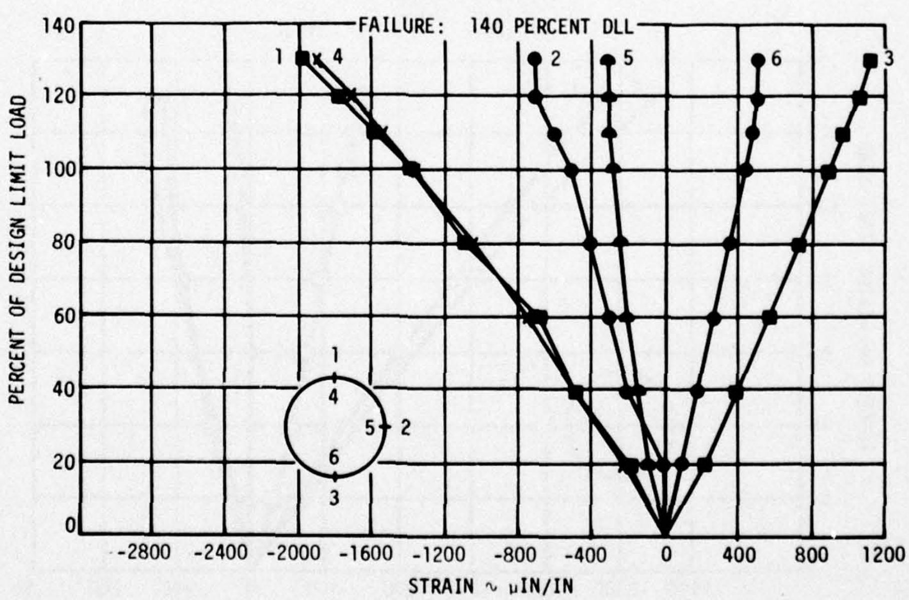


Figure 3.2-28. Cone 4 Longitudinal Strains at Station 6.0

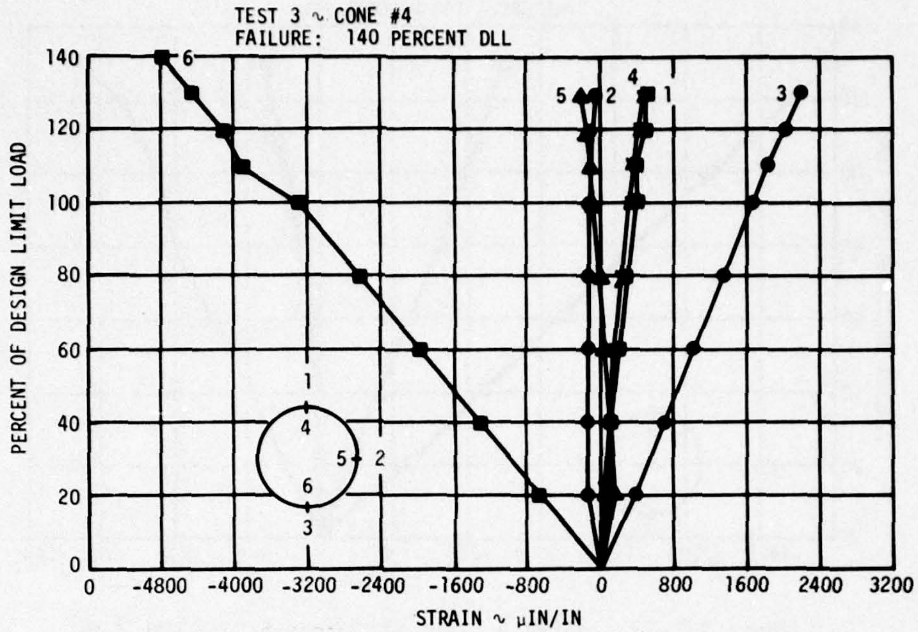


Figure 3.2-29. Cone 4 Hoop Strains at Station 6.0

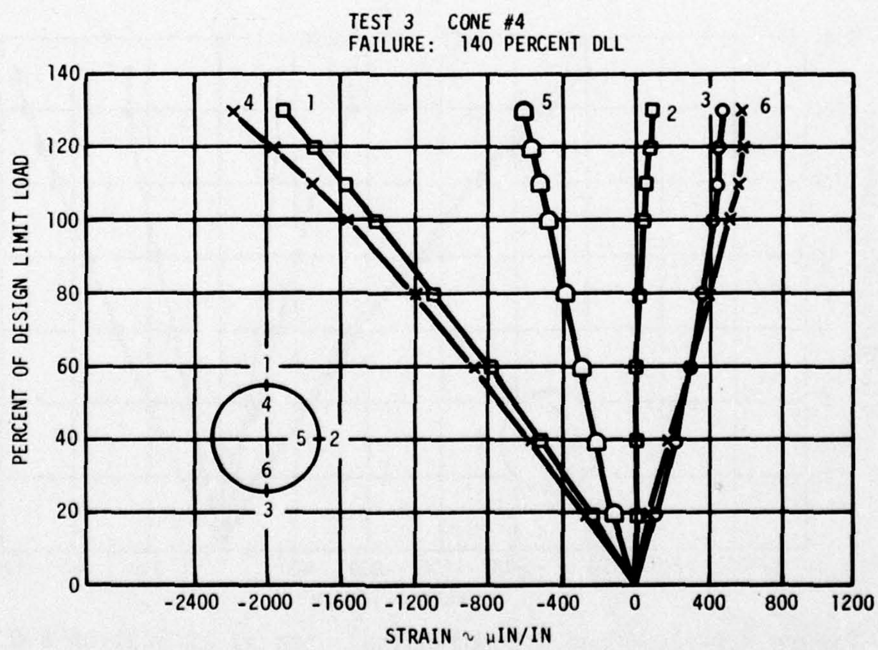


Figure 3.2-30. Cone 4 Longitudinal Strains at Station 9.60

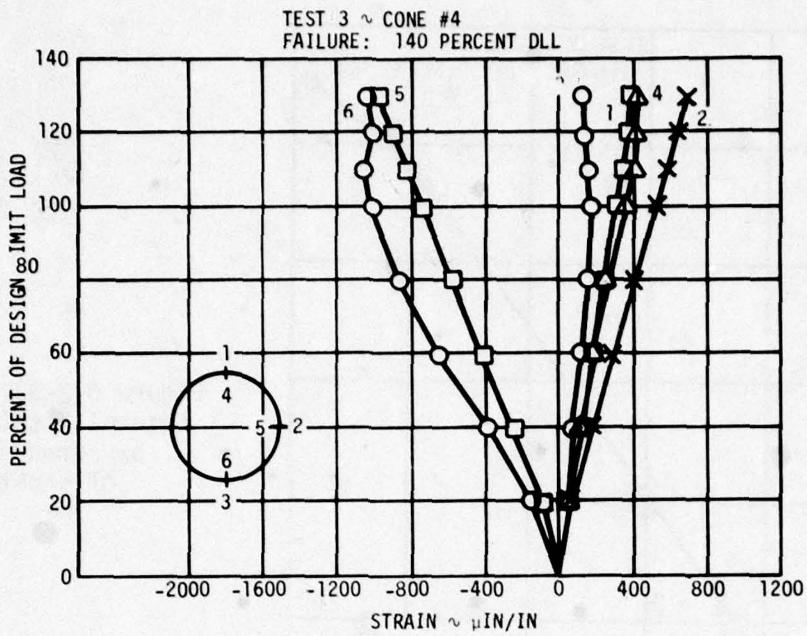


Figure 3.2-31. Cone 4 Hoop Strains at Station 9.60

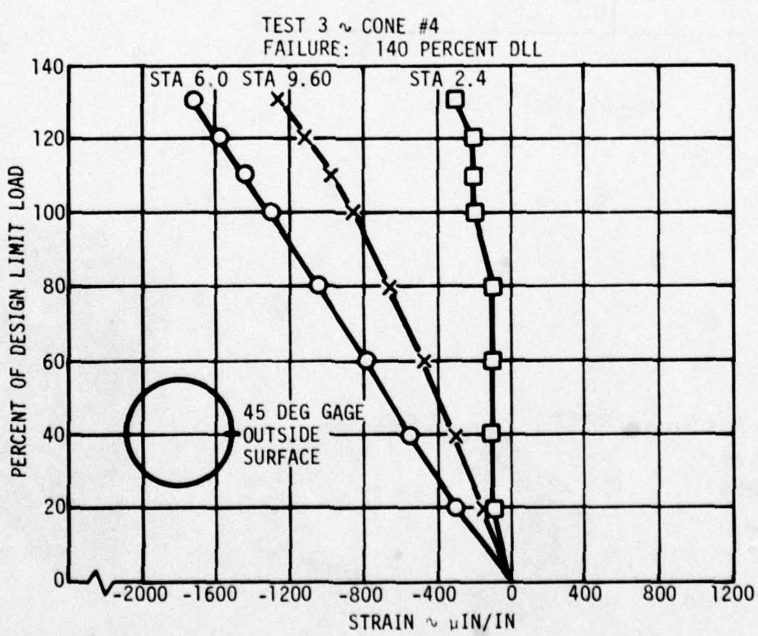


Figure 3.2-32. Cone 4 45 Degree Strains

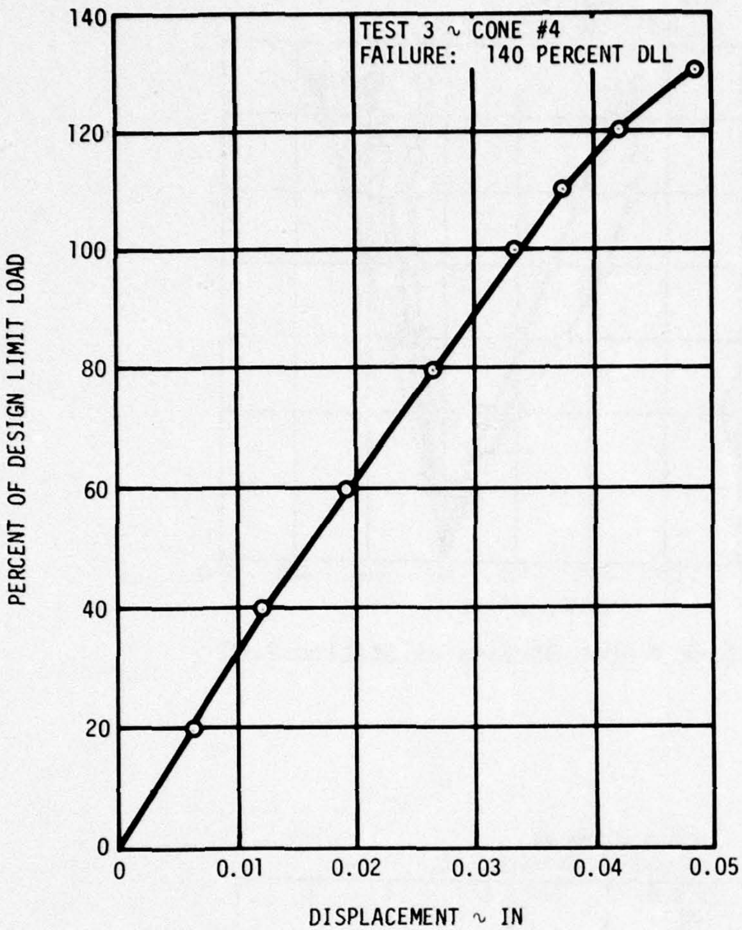


Figure 3.2-33. Cone 4 Lateral Displacement at Forward End of Frustum

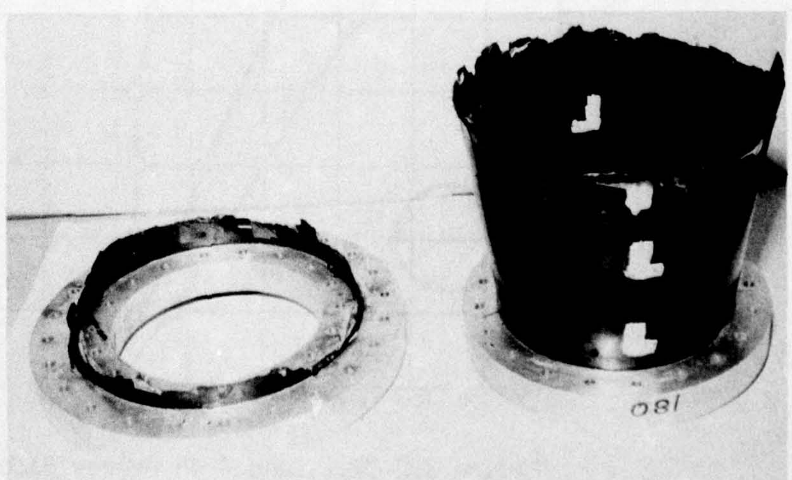


Figure 3.2-34. Failure of Cone 2 Under Combined Loads

At station 2.40, the strain data for the three test cones are consistent with a maximum longitudinal strain of -2200 μin/in and a maximum hoop strain of -2800 μin/in. Cone 2 (test 2) shows localized failure at 110 percent of DLL as evidenced by the discontinuity of strain in the hoop strain gages of cones 5 and 6 (Figure 3.2-19).

At station 6.0, a maximum longitudinal compressive strain of -2300 μin/in and a maximum hoop strain of -4800 μin/in were observed. In test 1, hoop gages at locations 2 and 3 show a large change of strains at 100 percent of DLL (Figure 3.2-13), signifying local failures. The large hoop strains were caused by the strap loads which imposed high bending strains at bottom of the shell as demonstrated by gages 3 and 6.

At station 9.6, where the maximum longitudinal strains occurred and fracture took place, cone 1 (test 1) exhibited discontinuous longitudinal and hoop strains at 100 percent of DLL, and failed at a lower load than cones 2 and 4. No abrupt changes in strains were found in cones 2 and 4. The maximum longitudinal and hoop strains are -2300 μin/in and -1800 μin/in respectively. Higher strains in the internal plies were predicted by analysis but could not be measured.

The 45 degree gages located at neutral axis of the three stations show strains which indicate shear deformations as resisted by the internal 45 degree plies. All shear strains are relatively low. In cone 2, the orientation of the 45 degree gage at station 9.6 was inadvertently misplaced by 90 degrees during installation of the gage. A positive strain was measured, whereas the others had negative strains.

The displacement at the free end under the combined loading after correction for fixture deflection is consistent for all three test cones. A transverse displacement of 0.042 was measured at 120 percent of DLL.

4.0 TASK 3 - PLAN FOR FURTHER DEVELOPMENT

4.1 Background

Graphite/epoxy composite structure technology for BMD interceptor applications has been under development for several years by AMMRC. This program addressed the feasibility of providing stiff lightweight structures for high velocity, highly maneuverable nuclear armed interceptors with two boost stages, such as the candidate 4c of the ATITP program (Reference 6). The graphite/epoxy (GY70/934) structures program has progressed through the subscale development, and with completion of the FY 79 contracts, will have demonstrated the feasibility of producing structures with reinforced splice joints, equipment mounting frames and shell cutouts.

Within the past year the BMD interceptor structures requirements have changed significantly from those of the ATITP generation of interceptors which provided the baseline for the subscale technology development. High bending stiffness requirements have been replaced by very high nuclear blast hardness as the governing design requirement. Furthermore, new structures issues and technology challenges are presented by the non-nuclear terminal homing interceptors. Specific interceptor strutures requirements will be forthcoming from two study contracts soon to be initiated by AMMRC, dealing with nuclear blast environments, blast test simulation, and non-nuclear interceptor structures and materials requirements. These requirements and the subscale structures technolgy will be integrated in the full scale technology validation program defined herein.

4.2 Development Objectives and Technical Approach

The overall objectives of the composite structures program are to develop and validate a full scale graphite/epoxy structures technology base for application to BMD interceptors. Specific technical objectives are to provide the design, analytical and manufacturing processes, and techniques required to produce high quality full scale structures, determine a rapid production capability for composite structures, and demonstrate through ground testing the ability of composite structures to meet BMD structures requirements.

The future development of graphite/epoxy missile structures would integrate the outputs of the Nuclear Hardened Interceptor Structures investigation (nuclear environment and blast effects simulation), the Non-Nuclear Kill-Millimeter Wave homing (NNK-MMW) interceptor structures and materials requirements study, and the graphite/epoxy composite structure subscale development (joints, frames, and cutouts) into the full scale development of a structural section typically representative of a blast hardened missile. This technical approach is illustrated by the development path shown in Figure 4.2-1 where the more important outputs of the 1979 studies preceding full scale development are listed.

In addition to these studies, a NNK warhead/structure interface test series to define fragment performance when being blasted through various structural materials is required to confirm the advantages of composite materials for the warhead section application.

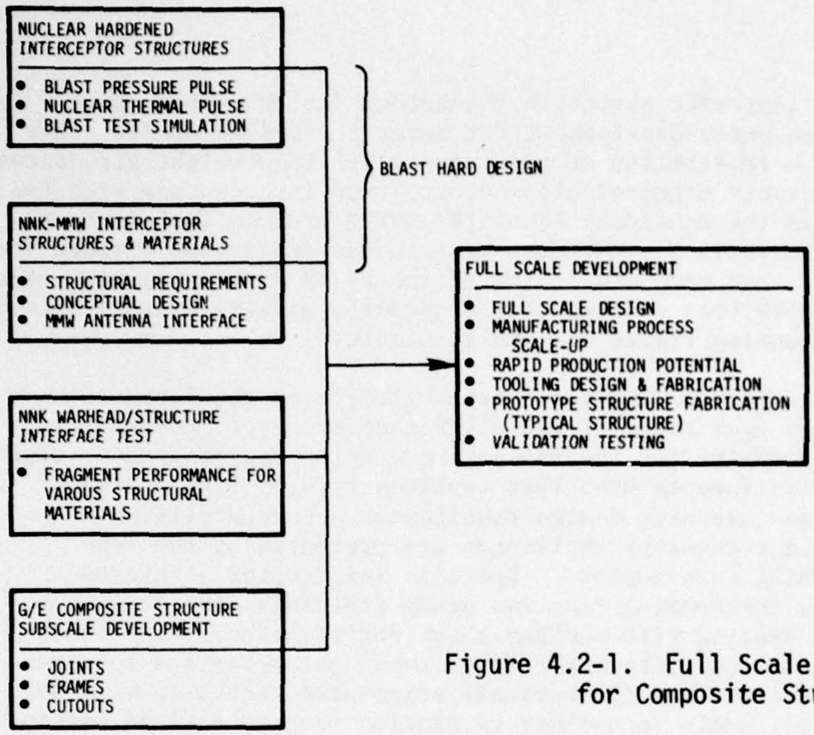


Figure 4.2-1. Full Scale Development Path for Composite Structures

The full scale development of graphite/epoxy structures would include full scale design, manufacturing process and tooling development, scale-up to full thickness, fabrication of test sections, and validation of the design and manufacturing procedures by subjecting the fabrication sections to simulated flight environments in ground test facilities. The transition from subscale to full scale development at this time is recommended so that full-size structures can be made available in the DNA high explosive test series MISTY CASTLE which has events scheduled for 1981 and 82.

4.3 NNK Warhead/Structures Interface Tests

Martin Marietta has demonstrated the feasibility of blasting NNK warhead fragments through composite structures (GY70/934) of the thickness range required for a NNK warhead section structure. However, prior to full scale development of composite structures, additional testing at the subscale level is recommended to demonstrate the advantage of composite materials over metallic structures in this application and to screen the relative performance of various types of graphite/epoxy material.

A series of six subscale tests similar to the Martin Marietta tests (Reference 7) would be required to meet the above objectives. Test 1 would determine baseline warhead performance with no structure. Tests 2 through 5 would fire steel fragments through aluminum, ultra-high modulus (UHM) graphite/epoxy, high modulus (HM) graphite/epoxy, and AS or HS type graphite/epoxy panels covered with a heatshield material. A sixth test

would be reserved for another material candidate. The structural panels for these tests would be designed to have identical blast hardness in terms of blast overpressure.

4.4 Full Scale Technology Validation

4.4.1 Full Scale Design and Analysis

Using the design loads and requirements emerging from the 1979 interceptor studies, along with the results of the subscale development and NNK warhead/structure integration tests, a typical interceptor structural section should be designed and analyses conducted. Rather than a specific interceptor design, this structure should be representative of the future application of composite structures to advanced BMD interceptors in size, frame geometry, splice joints, and blast hardness. Structural analyses would be conducted to assure a minimum thickness design that will provide the required blast hardness.

The full scale design should be coordinated with the manufacturing and tooling concepts that were sealed up from the subscale development program and should utilize the design techniques developed for splice joints, frames, and cutouts. The design task includes the heatshield design which will be incorporated into the structures for validation tests.

4.4.2 Manufacturing Technology Development

Full scale manufacturing development is recommended to establish the manufacturing processes and tooling required for full scale fabrication. Manufacturing process development would address the changes to the subscale processes necessitated by the increase in thickness and cone half-angle.

Scale-up of the manufacturing processes involves two very important considerations:

1 Change to the temperature/time history of the part prior to final cure.

2 The increased probability of residual stresses in thicker parts, especially for areas of discontinuities and for structures fabricated from ultra-high modulus graphite fibers.

Process development and tooling design will attempt to minimize these effects.

During tooling development, trial parts should be produced and evaluated by nondestructive testing (NDT) techniques and sample testing to assure that the collective tooling design and manufacturing processes produce a quality part prior to fabricating prototype sections for validation testing.

The full scale manufacturing technology development should consider mass production manufacturing techniques for graphite composite structures.

A rapid production capability should be determined and the required manufacturing processes and techniques identified. Production cost estimates using these processes would be provided.

Manufacturing process specifications for the full scale prototype fabrication should be established. These specifications also should be representative of mass (rapid) production techniques so that the resulting mechanical properties of the prototype structures and the validation test results are realistic.

4.4.3 Prototype Structure Fabrication

Utilizing the full scale tooling and manufacturing process specifications, prototype structures would be fabricated for subsequent validation testing. Fabrication of the full scale prototype structures should be completely documented by maintaining process records, material sampling, and NDT inspection records. Process histories should be kept on each section. Approximately 30 full scale sections will be required. Integration of the prototype structure and heat shield would be accomplished on 11 test sections slated for shock and nuclear blast testing.

Manufacturing cost data would be provided during the fabrication phase, and cost projections made for various production quantities. Breakout of production costs should include engineering, tooling, material (tooling and production), quality control, factory labor, and overhead.

4.4.4 Technology Validation Demonstration

Full scale validation of the advanced structure design and manufacturing processes can be accomplished principally in ground tests. Structural components, such as the primary shell, splice joints, and equipment and splice frames can be qualified by structural and dynamic shock testing to load levels simulating flight loading conditions. By demonstrating that the full scale prototype structures can survive the in-flight environments including nuclear blast encounter and still retain the mechanical properties required to complete the design mission, these structures would be validated for use in advanced BMD interceptors.

4.4.4.1 Static Tests

Static strength and stiffness of the full scale prototype structures would be characterized through a series of static load tests. Static test conditions should include both individually applied and combined loadings that would enable an interaction curve to be defined for combined bending and external pressure. A matrix of the static test phase of the validation testing, including the number of tests, output data, and required test facility capability is presented in Table 4.4-I. The estimated test facility requirement represents a capability 2.5 times the anticipated ultimate strength levels for the blast hardened structures.

TABLE 4.4-I

Validation Testing - Static Test Phase

Test Condition	No. of Tests	Estimated Test Facility Requirement	Output Data
Pure bending	3	6.6×10^6 in-lbs	• Shell bending stiffness • Splice joint stiffness • Bending strength • Strain and deflections
Axial compression	3	1.7×10^6 lbs	• Axial stiffness and strength • Strains and deflections
External pressure	3	5000 psi	• Ultimate pressure capability • Critical strains
Combined load-bending and external pressure	6	Moment=4×10^6 in-lbs Pressure = 4000 psi	• Strength capability for interacting bending and external pressure loadings • Critical strains
Critical flight loads	3	Simulated external and internal (inertial) loadings	• Strength verification and critical strains

Following the strength and stiffness characterization of the prototype structure, three tests to the critical design condition should be conducted. It is anticipated that this condition will be the nuclear blast encounter condition with high external pressure combined with bending, shear, and axial loads. Facility requirements for this test are expected to fall within the capability required to conduct the first four test conditions shown in Table 4.4-I; however, simulation of high inertial g loadings on internal equipment will be required.

A stress analysis of the prototype structure would be conducted for each test condition to establish a prediction of the failing loads. Strain gage data from the static tests will be correlated to the analysis and the test results compared to strength envelopes generated for the prototype structure.

4.4.4.2 Stage Separation Shock Testing

A full scale prototype structure should be subjected to a shock loading, simulating the maximum shock spectrum expected as a result of a stage separation using a flexible linear shaped charge. To determine the fragility level of the structures, this test would be conducted in a build-up manner with successively increasing acceleration magnitudes until the

design level is achieved. The test specimen should be instrumented with sufficient strain gages and accelerometers to provide meaningful data at various locations on the structure such as splice joints, equipment attach frame, etc. The shock machine should be calibrated to the predetermined shock increments prior to conducting the test.

4.4.4.3 Nuclear Blast Environment Simulation

The final phase of the technology validation consists of a capability demonstration of composite structures to withstand high pressure impulses, and the development and verification of response analysis computer codes. Simulation of nuclear blast encounter pressure impulses in ground test facilities is to be addressed in the Nuclear Hardened Interceptor Structures study. The candidate test techniques include large shock tubes, high energy (HE) explosives, and vented chamber explosions. The peak quasi--static pressure requirement is 500 psi with a positive phase duration of 80-100 milliseconds. At interceptor blast encounter, this high pressure results from the cumulative effects of initial manevering pressure, nuclear blast overpressure, density, and angle of attack changes. In ground test, the total pressure impulse must be generated by the test facility.

The blast pressure impulse test approach is 1) to conduct blast pressure impulse simulation tests in either the Sandia shock tube or the facility that emerges from the Nuclear Hardened Interceptor Structures study; 2) to submit full scale experiments for the high explosive test series MISTY CASTLE to be conducted by the Defense Nuclear Agency (DNA); and 3) to correlate the resulting test data to the simulated impulse tests and the structural response computer code analyses. For the purposes of structural response simulation, the pressure pulse only has to be long when compared to the natural periods of the structure. Therefore, it is possible that pulse durations on the order of 20-30 milliseconds may be acceptable. The natural periods of the composite structure test section will have to be determined prior to establishing test plans.

Prior to full scale composite structure testing, preliminary tests should be performed for pressure calibration of each facility. Two additional tests are also slated for the blast impulse simulation tests series for computer code calibration.

One blast effect to be investigated is the potential change in laminated composite structure deformational behavior resulting from the passage of shock waves through the composite. Investigation of this effect in full scale structure does not require the total pressure impulse shown above but does require the peak pressure shock wave impinging on the structure. This can be provided by detonating an explosive charge array at a predetermined standoff distance from the structure (economical and reliable technique that exists at Stanford Research Institute and the Martin Marietta SIMPULSE facilities). Post-blast strength would be determined by conducting structural tests to failure in compression test data (Section 4.4.4.1). Post-blast strength testing is also planned for those full scale structures tested in the pressure impulse simulation tests.

Nuclear blast environment validation must also include development and verification of an analytical, computerized structural response code, including modeling of the pressure pulse. The test pressure pulses should be modeled in conjunction with pressure calibration testing. A structural math model would also be developed for use in the response code. The response code would be calibrated or tuned in conjunction with the blast pressure simulation testing. The result would be not only definition of the graphite composite structural response to simulated nuclear blast environments, but also an analytical capability to determine the influence on blast response due to future changes of the structural design or the blast environments.

TEST FACILITIES

The DNA high explosive test series MISTY CASTLE has two events that could be used in the full scale composite structure validation. The first, event 2, is a 600 ton shot tentatively set for June 1981 at a southwest test site. This shot specifically supports Army requirements. Event 3 is scheduled during 1982 at an Army installation (not yet specified). The explosive size for this shot has not been established.

The large scale HE event most closely approximates the nuclear encounter. With the addition of the inertial loader device the simulation approaches the encounter even more closely. In this respect, this type of test is quite advantageous. The cost of fielding the graphite/epoxy blast test experiment should be reasonable. There is some risk involved since jetting (non-circular expansion of pressure isobars due to irregular burning of the large-size explosives) can cause significant variation of overpressure. The effect of dust caught up in the air, increasing the density, is another possibility presented by this type of test. Because of the above technical risks, it is recommended that two test specimens be fielded for each event. The specimens should be released just prior to the blast to reproduce the free flight end conditions, or the specimen can be mounted on the Martin Marietta inertia loading device to simulate maneuver accelerations. If the latter is chosen, a foundation must be built at the test site and the inertia loader must be shipped. Although this presents no difficulty technically, it would add to the cost of the testing.

The Sandia blast tubes have the capability of providing long duration pulses as compared with the sheet explosive or primer cord tests. The test facility has been in use for many years and the crew has compiled extensive experience in this type of test. The data acquisition system is more than adequate. The facility requires about six months lead time which can be shortened depending on the amount of fixturing required.

The test is set up with the specimen mounted in a tube so that the blast wave impinges at the desired angle. The specimen is then cut loose so that it is in a free condition as the blast wave hits. It is then forced out of the tube by the dynamic pressure loading. The instrumentation lines are active until the specimen is forced out of the tube.

The Martin Marietta SIMPULSE facility provides the ability of simulating a blast encounter occurring during a maneuver. The pulse amplitude and circumferential distribution can be matched by the proper configuration of explosive material. Repeatability is high and the costs are reasonable. The SIMPULSE facility includes all the data acquisition equipment required-high-speed camera, strain gages, accelerometers, pressure transducers, timimg reference, bridge and charge amplifiers, tape recorder, on line shock spectrum analyzer and x-y plotter.

The test is set up with the specimen mounted on the table and driven into an arrestment device, producing inertial loading simliar to the maneuver loads. During this acceleration, a blast wave engulfs the specimen. The blast wave is generated by detonating an array of primer cord or sheet explosives. The wave front is established by timing the detonation front to initiate the explosives in a uniform manner. This timing may be accomplished by equal length explosive trains or other techniques such as light sensitive explosive sheet.

Three different test articles would be manufactured in accordance with Table 4.4-II.

TABLE 4.4-II

Specimens

Specimen Type	Number Required
Pressure calibration	1
Computer calibration	1
Full scale section	10

The pressure calibration specimen would be a steel frustum, partially filled with concrete. A forward and aft fairing would be added to preclude improper loadings on the ends. Radial tubes, spanning the annular concrete would serve as passages for instrumentation cables. Five rows of 16 pressure transducers would be mounted in the calibration section and one row of 16 pressure transducers would be mounted in the aft fairing. A sketch of this specimen is shown in Figure 4.4-1.

The computer code calibration section (Figure 4.4-2) would be a graphite/epoxy conical frustum with similar forward and aft fairings to the pressure calibration section. There would be no internal masses of stiffeners and no cutouts. Four stations would be instrumented with strain gages and three stations would contain accelerometers. The instrumentation channels are summarized in Table 4.4-III.

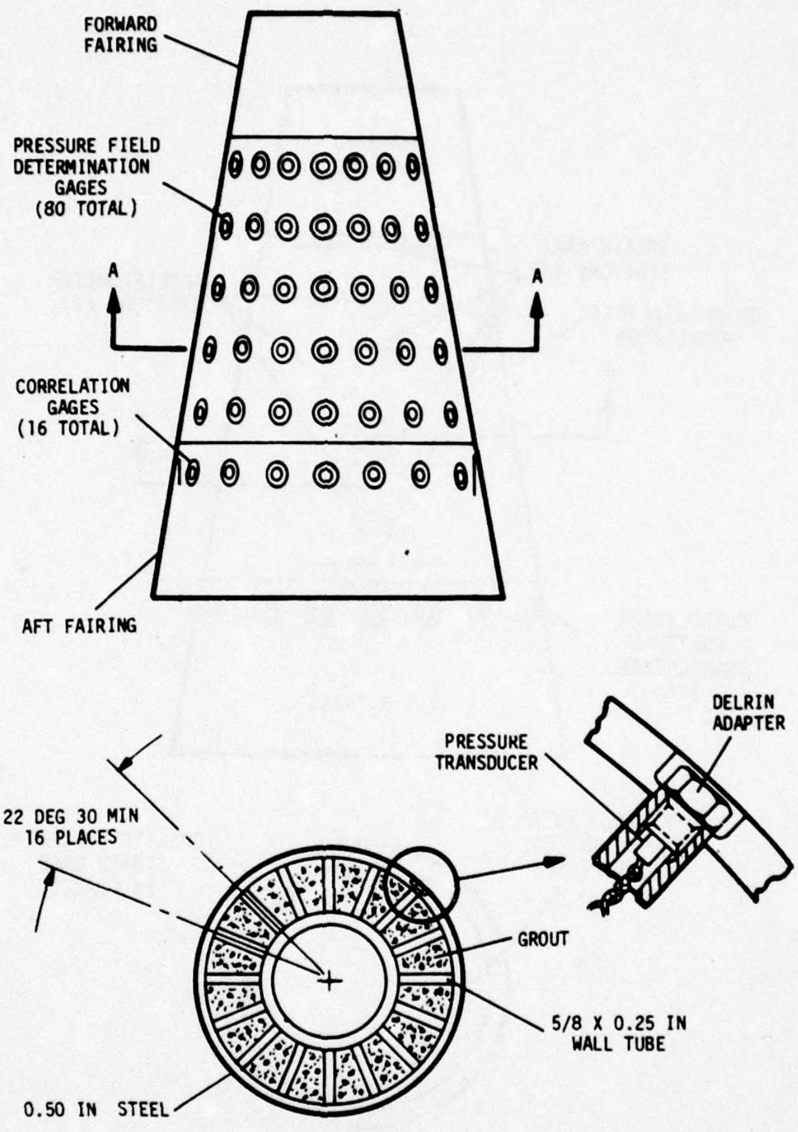


Figure 4.4-1. Pressure Calibration Specimen

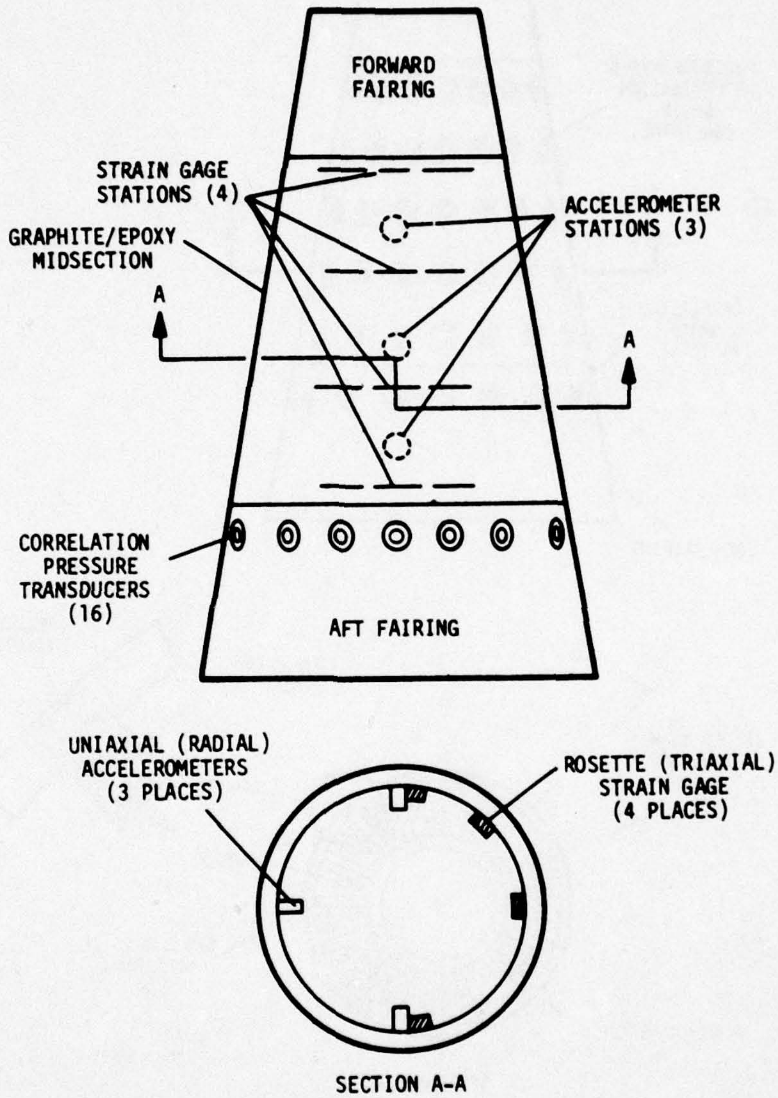


Figure 4.4-2. Computer Code Calibration Specimen

TABLE 4.4-III

Instrumentations

Specimen	Pressure	Acceleration	Strain	Total
Pressure calibration	96	0	0	96
Code calibration	16	9	48	73
Full scale	16	TBD	TBD	TBD

The full scale test specimen (Figure 4.4-3) would include the typical section designed earlier in the program containing splice joints, equipment frames and dummy inertial masses. Strain gages and accelerometers would be installed in addition to the correlation pressure gages. The graphite/epoxy section would have a heat shield and any cutouts would be filled with dummy antenna/windows.

The specimen designation is shown in the test matrix presented in Table 4.4-IV.

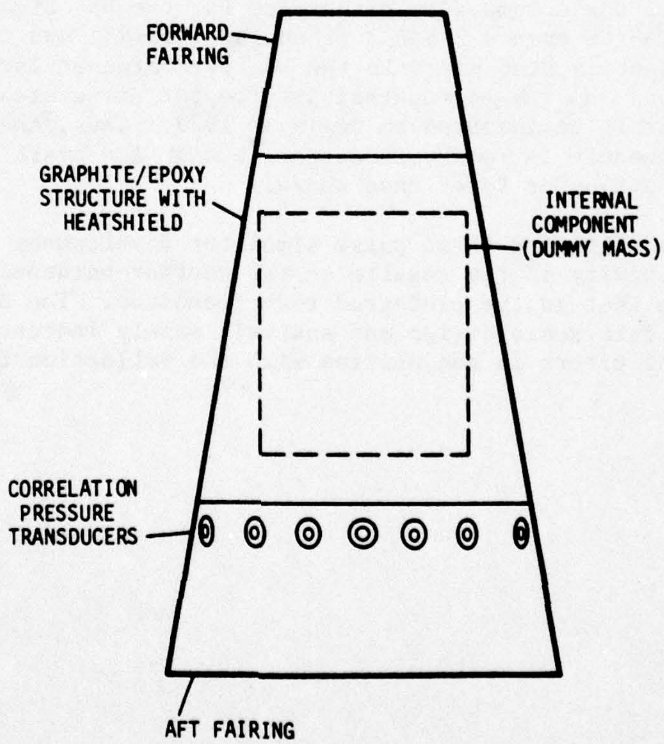


Figure 4.4-3. Full Scale Test Specimen

TABLE 4.4-IV

Nuclear Blast Test Simulation Matrix

	Specimen Designation			Number of Tests			
Test	Pressure Calibration	Code Calibration	Full Scale	Pressure Calibration	Code Calibration	Full Scale	Total Tests
High explosive (MISTY CASTLE)	P-1	-	1-4	2	-	2	2
Impulse simulation (EG, Sandia shock tube)	P-1	C-1	5-7	4	2	3	9
Blast Shock (EG, Simpulse)	P-1	-	8-10	4	-	3	7
Post-blast strength (Structures Lab)	-	-	5-10	-	-	6	6

4.4.5 Full Scale Development Schedule

A schedule for the full scale development of graphite composite missile structures is presented in Figure 4.4-4. This schedule is designed to provide full scale composite structures for the DNA high explosive test series MISTY CASTLE events 2 and 3 scheduled for 1981 and 1982. The full scale development is also keyed to the Nuclear Hardened Interceptor Structures study and the non-nuclear interceptor structures requirements contract currently anticipated to begin in 1979. Thus, the full scale development schedule is constrained at both ends and start dates on these programs must not occur later than shown.

The dotted line for blast pulse simulator development provides time for such an activity if the results of the nuclear-hardened structures study indicate that is the preferred test technique. The dotted line extention for full scale design and analysis merely indicates an intermittent analytical effort in conjunction with the validation testing.

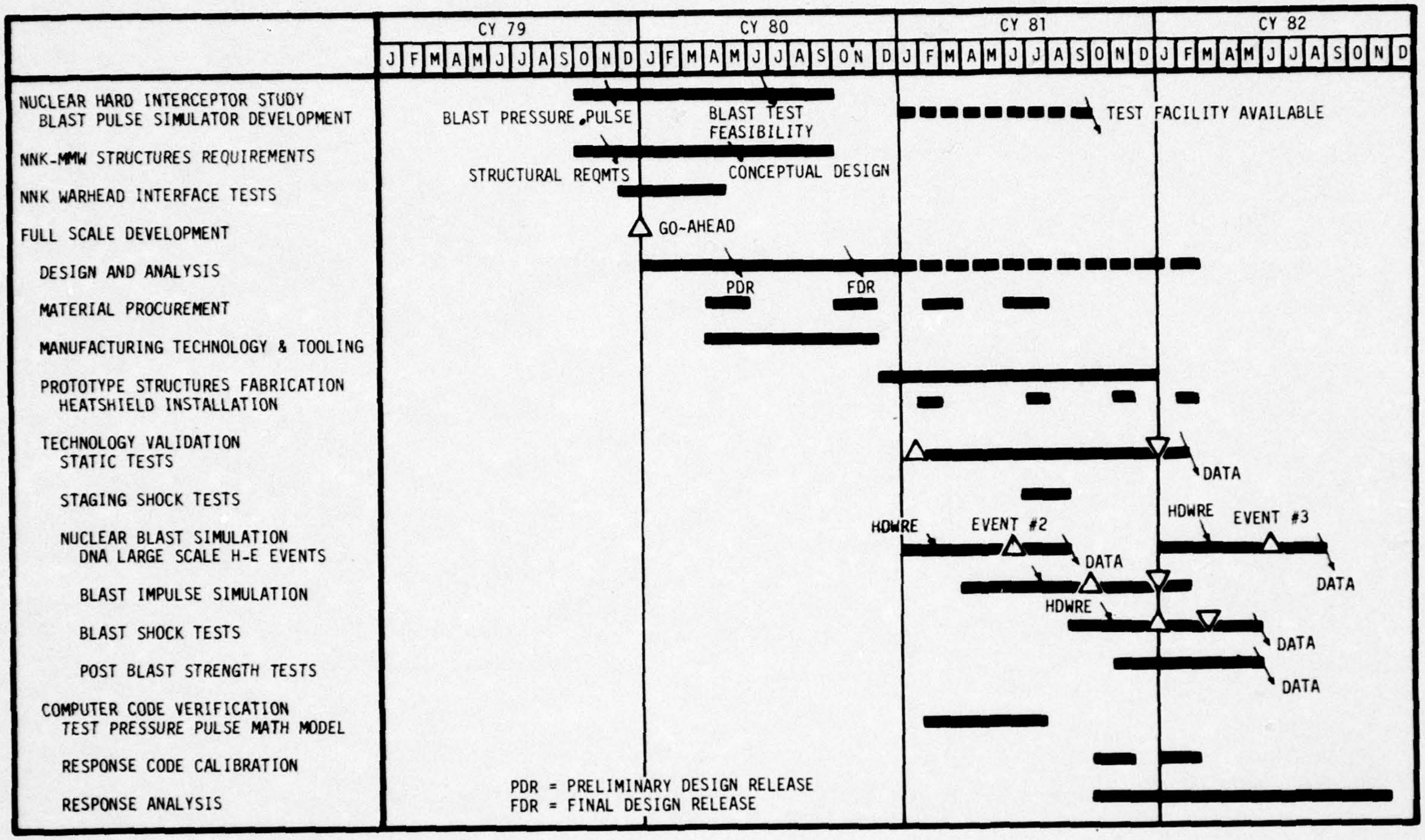


Figure 4.4-4. Full Scale Development and Validation Schedule

5.0 CONCLUSIONS AND RECOMMENDATIONS

The test and evaluation of GY70/934 subscale conical frusta resulted in the following conclusions:

1 Conical frusta fabricated from GY70/934 ultra-high modulus graphite/epoxy prepregnated tape per the Martin Marietta process specification SPC10720729-001 meet or exceed the design requirements.

2 Strength variation within ± 8 percent of the average can be expected. Data from both axial compression and combined loads testing exhibited this characteristic.

3 The analytical strength prediction technique using the SQ-5 computer program produces reasonable although conservative results. With the exception of one combined load test (cone 1) which failed at 93 percent of the predicted strength, all other tests demonstrated strengths in excess of the analysis by margins of 1 to 10 percent.

4 These tests reaffirm that GY70/934 laminated shells can carry increased loads after the initiation of local internal failures by virtue of the redistribution of loads within the laminate.

5 The initial compressive modulus of elasticity is less than the theoretical value. This is expected since the theory assumes perfect fiber alignment, whereas in practice a four-gore pattern of zero degree fibers actually has an average angular alignment of 2.75 degrees. The measured modulus from test data closely follows the rule-of-mixtures method of predicting laminated composite stiffness.

6 The compressive strength of the conical frustum is sensitive to the wall thickness. The test data indicated a rough correlation of increasing strength to an increase in wall thickness.

7 It was not possible to conclusively isolate the effects of microcracking on the cone performance within the type of testing conducted in this program. The largest variation of the frequency of microcracks occured in the axial load test cones 3, 5, and 6 with cone 6 having the least cracking. Since cone 6 also failed at the lowest load, it is apparent that the thickness effect overshadows any effects from microcracking.

8 The deviations in the compaction processes utilized in the fabrication of cone 6 did not improve the fiber/resin ratio or compressive strength and may have been counter-productive because of the resulting reduction in wall thickness.

The fabrication of six subscale conical frusta from GY70/934 graphite/epoxy has led to the following recommendations for improvement in future manufacturing efforts:

1 Better fiber uniformity should be obtained in source material. The gaps in the FY70 fiber used in the development program permit local pockets of pure resin which lower the mechanical strength levels and contribute to higher than optimum resin content and reduced process control.

2 If the existing resin system is required due to its higher service temperature capabilities, use of a scrim layer of 104 fiberglass cloth over the exterior faces of the laminates and at the 14th ply within the interior should be considered. This would inhibit initiation of microcracking in the 0 degree multi-ply laminae and prevent handling, scuffing, and scratching from damaging the exposed structural reinforcement fibers at the surfaces.

3 A complete 0 degree fiber layer wrap should be layed out in the flat on mylar film patterns covered with tedlar as a release layer. All 3-inch gore patterns should be cut alike for the 0 degree plies, thereby reducing the off-elemental angles of fibers at the joints to one-half the present angles. This scheme would not be practical for the 45 and 90 degree oriented plies.

The plan for future development of graphite/epoxy composite structures includes a number of recommendations:

1 A transition from subscale to full scale technology development is recommended so that full size structures are available in the (DNA) high explosive test series MISTY CASTLE which has events scheduled for 1981 and 1982. These tests would be an integral part of the full scale validation program for graphite/epoxy composite structures.

2 Since the step up to full scale development requires new tooling, the composite structure program can be updated to reflect the new configurations and requirements with the least impact at this point in the program. An update of the structural configuration at this point in the program will also provide more realistic results in the full scale validation testing.

3 Prior to full scale development of composite structures, NNK warhead/structures interface testing at the subscale level is recommended to demonstrate the advantage of composite materials in this application and to screen the relative performance of various types of graphite/epoxy composite materials.

4 The full scale development and validation of the composite structure technology should be conducted on a typical interceptor section that is representative of the future application of composite structures to advanced BMD interceptors in size, frame geometry, splice joint, and blast hardness design.

5 Full scale manufacturing development is recommended to establish the manufacturing processes and tooling required for full scale fabrication. Changes to the subscale processes necessitated by the increase in thickness and cone angle should be addressed. A rapid production capability should be determined and the required manufacturing processes identified.

6 Full scale technology validation testing should be conducted to investigate the potential change in laminated composite structure properties resulting from the passage of shock waves through the composite due to high overpressure nuclear blast encounters.

7 Nuclear blast pressure impulse should be simulated in both a (yet to be identified) test facility and in the DNA high explosive test series MISTY CASTLE.

8 Nuclear blast environment validation should also include development and verification of an analytical, computerized structural response code, including modeling of the pressure pulse. The test pressure pulses would be modeled in conjunction with pressure calibration testing. A structural math model would also be developed for use in the response code. The response code would be calibrated or tuned in conjunction with the blast pressure simulation testing. The result will be not only definition of the graphite composite structural response to simulated nuclear blast environments but also an analytical capability to determine the influence on blast response due to future changes of the structural design or the blast environments.

REFERENCES

1. AMMRC TR 78-4 "Subscale Development of Advanced ABM Graphite/Epoxy Composite Structure" - Final Report, Contract DAAG46-75-C-0097, January 1978, Martin Marietta Corporation.

2. OR 15,153 "Advanced Structures Prototype Phase I Final Technical Report",- Vol I, Contract DASG60-77-C-0111, Ballistic Missile Defense Advanced Technology Center, August 1978, Martin Marietta Corporation.

3. OR 14,859 (Addendum) "Advanced Structures Prototype - Phase I Conical Shell Test Plan", Contract DASG60-77-C-0111, Ballistic Missile Defense Advanced Technology Center, March 1978, Martin Marietta Corporation.

4. SQ-5 "Point Laminate Stress Analysis Program", General Dynamics - Fort Worth Division.

5. ANA 74700314-001, Rev B "Preliminary Materials Specification, Graphite/ Epoxy Prepreg", Contract DAAG46-75-C-0097, Army Materials and Mechanics Research Center, January 1978, Martin Marietta Corporation.

6. OR 12,393 "Advanced Terminal Interceptor Technology Program" (U) Final Report, Contract DAHC60-72-C-0022 (P00002), US Army Safeguard System Command, April 1973, Martin Marietta Corporation.

7. OR 15,287 "Fragmentation Warhead/Structures Interface Study" (U), Contract DASG60-77-C-001, Ballistic Missile Defense Systems Command, October 1978, Martin Marietta Corporation.

APPENDIX A

PRELIMINARY MANUFACTURING PROCESS PLAN FOR FABRICATING GRAPHITE/EPOXY SHELL STRUCTURES

1.0 SCOPE

1.1 Application - This process presents the general requirements, procedures, and controls for the fabrication of unidirectional graphite fiber reinforced epoxy laminated structural parts intended for aerospace applications. Specifically, this process describes the requirements and establishes the procedures and controls for layups, debulking, compaction and curing techniques employed in fabric conical shell structures.

1.2 Composite Types - Individual graphite fiber/epoxy composite structures are defined by the particular graphite fiber and epoxy systems used and the construction methods called out by the Engineering drawing and applicable process specifications. Because of the interdependency resin systems, fiber types and processing methods specified, no substitutions of materials or processing sequences shall be permissable without engineering approval.

This process provides instructions for employing GY70 ultra-high modulus fibers (Celanese Corp.) and 934 resin system (Fiberite Corp.) in the fabrication of composite structures.

1.3 Applicability - This process shall be applicable when specified authorizing documents. Materials, procedures, and equipment specified herein shall be used.

1.4 Authorizing Documents - The authorizing documents shall specify the following fabrication and inspection criteria:

a The configuration, layup sequence, material and fiber direction of each ply of each part.

b The cure cycle for the composite, including times, pressures, temperatures, and heating and cooling rates.

c Configuration, material, and location of inserts or attached fittings. A cleaning method will be specified for inserts/fittings where applicable.

d Physical properties test requirements. The number, configurations, and locations of test coupons will be indicated.

e Permissibility of compaction and/or debulk cycles and vacuum bagging systems.

f Visual acceptance requirements and non-destructive test criteria, as applicable.

g Weight or areal fiber weight for critical application.

1.5 Special Skills - The operations described in this process require special skills. Personnel performing these tasks shall be certified in accordance with Standard Procedure 123.1, Plastics, Composite, Fabrication, and Inspection.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents form a part of this process to the extent specified herein.

2.1.1 Martin Marietta Manufacturing Processes

MP65404	Composite Graphite Fiber/Epoxy Structural Parts, Fabrication of
MP50046	Degreasing, Vapor

2.1.2 Martin Marietta Standard Procedure

123.1	Skill Certification

3.0 MATERIALS

Items marked with an asterisk (*) are hazardous materials. Refer to Section 7 of this process for special precautions and procedures to be followed when handling these materials.

3.1 Resin Impregnated Graphite Materials - The basic graphite/epoxy material is supplied in the form of B-stage uncured prepreg graphite fiber tape. The prepreg graphite material covered by this process is listed in 3.1.1.

3.1.1 Unidirectional Graphite Fiber Tape (GY70/934)

(Impregnated with epoxy resin system)

Spec: ANA 74700314-001 Rev. B, Type 5, Class 4

3.2 Glass Cloth Material - The glass cloth materials supplied for laminate construction must have resin system and cure cycles compatible with 3.1.1 materials.

3.2.1 Woven Fiberglass Cloth

Spec: STM H665 Type 1 104E glass cloth (scrim)

Type 2 112E glass cloth

Type 3 Other cloth forms

Code: H665A (104 cloth)

H665B (112 cloth)

3.3 Tape, shrink 0.002 in thick x 1.00 in wide
Source: Dunstone Company, Elk Grove, Wisconsin
Spec: Commercial

3.4 Ceara wax
Source: Ceara Products, Inc.
Denver, Colorado 80217
Spec: Commercial

3.5 Tape, glass, aluminized
Spec: STM J505
Code: J505A100 RL

3.6 Film, nylon, vacuum bag grade (0.002 in thick)
Source: Cadillac Plastic Company
Spec: Commercial
Code 05582600RL

3.7 Film, FEP, Type R, nonperforated, 0.001 in thick
Spec: Commercial
Code: 05582800RL

3.8 Film, FEP, Type PR, perforated
Spec: Commercial
Code: 05582700RL

3.9 Fabric, parting, Trevarno #183018
Spec: Commercial
Source: Coast Industries, California

3.10 Fabric, glass, Style 161, volan finish (Brunswick 7532 or 7544)
Spec: Commercial
Code: 05077800RL

3.11 Sealant, vacuum bag, GS213
Spec: Commercial

3.12 *Solvent, methyl ethyl ketone (MEK)
Spec: TT-M-261
Code: K527A100GL

3.13 *Solvent, acetone
Spec: 0-A-51
Code: K528A100GL

3.14 Cheesecloth, unsized, oil free
Spec: Commercial
Code: 05077710RL

3.15 Film, Polyethylene
Spec: L-P-378 Type 1, Grade A, Finish 1
Code: A623A060 (Roll 0.006 in thick x 72 in wide)

3.16 Foam, Polyurethane 1 in thick
Spec: Commercial
Code: A C406

3.17 Adhesive, structural bonding film
Spec: STM M471
Code: M471 B

3.18 Adhesive, epoxy paste
Spec: MMM-A-132 TY1 CL3
Code: M434 D

3.19 Release-All #30
Source: Airtech International Inc, Torrance, Calif. 90509
Spec: Commercial

3.20 Polyethylene bristle brush
Spec: Commercial

3.21 Pasa-Jell 107
Source: SEMCO, Division of Product Research and Chemical Corp.
Spec: Commercial

3.22 Litmus Paper
Spec: Commercial

4.0 EQUIPMENT

4.1 Autoclave, temperature range to 400°F, pressure range to 125 psi and chamber capacity to accommodate part.

4.2 Pump, vacuum, capable of continuous operation at 27.5 inches Hg, minimum, at sea level equipped with calibrated vacuum gauge.

4.3 Oven, air circulating, temperature range to 400°F with ± 10°F control accuracy.

**4.4 Freezer, capable of maintaining $0^{\circ}{}^{+0^{\circ}F}_{-10^{\circ}F}$.

**4.5 Refrigerator, capable of maintaining 40 ± 5°F.

4.6 Gloves, lint free cotton or nylon. Tool crib item.

4.7 Heat gun, tool crib item.

4.8 Shop aids - Plastic paddles (Teflon), rollers, paper cutter, scissors, utility knives, as required.

4.9 Gloves, polyethylene
Code: 05582900 large

4.10 Goggles, safety, tool crib item.

**Units shall be equipped with calibrated temperature recorders.

4.11 Vent hood for abrasive cleaning

4.12 Respirator/face mask - tool crib item.

Autoclaves, ovens, and furnaces shall be certified by Quality Engineering. Temperature recorders and temperature indicating devices shall be calibrated by Quality.

5.0 PROCEDURE

5.1 Requirements

5.1.1 Finished Product Appearance and Construction Properties

5.1.1.1 Foreign Materials - No visible foreign materials shall be present in the finished part. Small non-metallic lint particles, 0.060 inch or less in any dimension, which are found in the raw material (prepreg) shall be acceptable provided they do not extend to the surface of the cured laminate.

5.1.1.2 Gaps and Laps

5.1.1.2 Gaps and Laps - There shall be no gaps between any lamination except as specified on the engineering drawing. No two parallel laps shall be superimposed upon each other except as specified on the engineering drawing.

5.1.1.3 Wrinkles - There shall be no wrinkles in the finished part except as permitted by the engineering drawing. The wrinkled material, where allowed, shall be sound and free of voids and delamination, as determined by visual examination.

5.1.1.4 Breaks and Cracks - There shall be no breaks or cracks in any part of the laminate.

5.1.1.5 Delamination, Blisters, and Voids - There shall be no delamination, blisters, or voids as determined by unaided visual examination.

5.1.1.6 Porosity - There shall be no pores that extend into the laminate on critical surfaces. All surface fibers shall be covered with a uniform and even coat of resin.

5.1.1.7 Resin Starved Areas - There shall be no starved areas. Starved areas are areas in which the laminate is not uniformly coated with resin (also called pitting or worm hole).

5.1.1.8 Resin-Rich Areas - Resin-rich areas are evidenced by an appreciably darker color than the remainder of the laminate. These areas shall be considered acceptable provided that dimensional tolerances are met and that there are no associated defects in these areas such as crazing, cracks, blisters, voids, or delaminations.

5.1.1.9 Disoriented Fibers - Unidirectional fibers shall be continuous and uniformly oriented within individual plies. No lateral buckling or disorientation of the fibers shall be permissible unless otherwise stated on the engineering drawing.

5.1.1.10 The dimensions of the finished part shall be within the tolerance specified on the engineering drawing.

5.1.1.11 Microscopic inspection at 80 to 100 x of a representative cross-section of the referee/tag-end sample of cured laminate, when cut and polished by metallographic techniques with 600 grit or finer abrasive, shall show a tightly compacted laminate structure with:

a No gaps between structural fiber joints greater than 0.020 inches.

b No separation between laminate layers greater than the cured ply thickness.

c No kinks or wrinkling of the structural composite layers.

d No superposition of parallel layup ply joint areas.

e No indications of reinforcement breakage or resin crazing, cracking, or delamination.

f No combination of voids in excess of 2% of the total cross section area being examined. Use visual inspection aids.

5.1.2 Mechanical Properties - Mechanical properties of the laminate system shall be determined from referee samples fabricated with the production part/parts. Mechanical properties tests and requirements shall be as noted on the engineering drawing.

5.1.3 Physical Properties

5.1.3.1 All surfaces shall be hard and free of tackiness after cure.

5.1.3.2 Resin content of the unidirectional tape and sheet plies of the laminate shall be greater than 35 percent and shall not exceed 50 percent by weight.

Resin content tests shall be conducted upon samples fabricated with the production part and in accordance with ASTM method D 3171-73.

5.1.3.3 The cured composite weight and/or a real fiber weight shall be as noted on the engineering drawing.

5.1.3.4 The weight of the finished part shall be within the limits specified on the engineering drawing.

5.1.3.5 Void content of the composite part shall not exceed 2% in any visually examined section.

5.1.4 Molding Method - Molding method shall be autoclave cure with pre-cure laminate compaction and/or debulk for flat or conical parts.

5.1.5 Work Areas - Work areas shall be maintained in a clean and orderly condition. Emphasis shall be placed on the following requirements:

a Area shall conform to Manufacturing Practice 99.991, Code 5, with the exception that layup areas shall be temperature controlled to $70 \pm 5°F$.

b The area shall be enclosed and separate from dust-generating or manufacturing areas which are not cleanliness-controlled.

c Air supplied to the area shall be from a filtered source.

d The area shall be suitably posted as a contolled area: LIMITED ACCESS AREA, AUTHORIZED PERSONNEL ONLY.

e Maintenance schedules shall be established as follows:

1) Trash shall be picked up daily.

2) Floors shall be oil mopped regularly and once a week floors shall be wet mopped.

3) Air vents shall be cleaned as necessary to maintain a clean working area.

4) The work area, including windows, doors and door frames, shall be cleaned as scheduled by maintenance or upon request.

f Silicone containing compounds shall be prohibited from contact with layup materials.

g Tools and Equipment - All tools (e.g., shears, knives, rollers, etc.) shall be solvent wiped with clean cheesecloth moistened with MEK or acetone before use.

h Eating and smoking shall be restricted to designated areas as far removed from the layup area as possible.

i Particle generating operations (drilling, routing, sanding, machining, etc) which are associated with manufacturing operations of this specification shall be conducted in areas remote from layup operations to ensure that particulate materials do not contaminate the articles under fabrication.

5.1.6 Material Handling - Polyethylene gloves (4.6) may be worn when handling pre-pregs. Handling of pre-pregs with bare hands is permissible, but should be minimized to prevent allergic reactions. When handling pre-pregs with bare hands, the operator's hands must be washed thoroughly

with soap and water before and after handling. Clean white gloves (4.6) shall be worn when handling cleaned inserts/fittings but shall not be used to handle pre-pregs due to possible lint deposits and contamination.

5.1.7 Storage of Pre-preg Material (3.1)

The pre-preg material shall be stored in a freezer (4.4) and controlled as follows:

a The pre-preg shall be sealed in a vapor proof bag and stored at a temperature of 0°F or lower.

b When pre-preg is removed from cold storage, it shall be permitted to stabilize at room temperature until moisture condensation on the outer surface of the bag ceases.

c The amount of pre-preg removed from the freezer shall not exceed the amount required for one shift's work unless it is part of a continous roll of material. If usage on successive days is anticipated, material may be returned to storage at 40°F maximum.

d Each batch of pre-preg shall have a valid shelf life sticker attached.

e A record of pre-preg temperature history shall be maintained when required by controlling documents.

PQVR-1a Verify that pre-preg is within storage life date and record batch number in the Manufacturing Process Plan (MPD).

5.1.7.1 The pre-impregnated material may be warmed to facilitate draping on tools. The detail manufacturing process plan shall specify method, maximum temperature, and time limits of heating for each part.

5.1.8 Mandrels - Prior to using a mandrel for parts layup, a visual inspection shall be made of mandrel surfaces to insure freedom from pits, gouges, or surface irregularities which would result in unsatisfactory surfaces on the finished part or which might damage the part during mandrel removal.

PQRV-1b Quality shall insure that the production mandrel meets engineering dimensional and surface finish requirements prior to usage.

* 5.1.9 Fabrication Log - Record sheets shall contain necessary process controls including procedure for determing cure temperature related to the molding operation. (A sample log sheet is shown in 8.0).

* 5.1.10 Detail Process Plan

A manufacturing plan shall be prepared which specifies the parameters of the detail process procedures. This document shall be traceable by

data, shall be approved by the Quality Assurance and shall include but not be limited to the following: (A sample plan is shown in 9.0)

a Applicable engineering drawings

b Number and orientation of plies in laminate

c Layup materials and sequence

d Compaction/debulking instructions and steps

e Pre-cure, cure, and postcure requirements and procedures

* The detail level of documentation and format shall be determined by Program Management. Paragraphs 5.1.9 and 5.1.10 are recognized as sample formats and requirements only.

5.1.11 Vacuum Bagging - The vacuum bag for flat and conical shapes process methods shall be applied and checked for leaks prior to heat-up or augmented pressure application. Adequate vacuum outlets shall be used to ensure removal of volatiles during cure. As a minimum the following shall be used:

a Two vacuum source outlets shall be provided for up to 10 ft^2 of part area.

b One additional source outlet shall be provided for each additional 10 ft^2 of part area or fraction thereof.

c A minimum of one vacuum static outlet shall be provided for each part for measurement of the pressure under the bag.

d The vacuum and static hoses shall be a minimum of 1/4 inch internal diameter.

5.1.12 Mold Release - Mold release materials shall not contain silicone oil, silicone compounds, or other materials that will contaminate the part. The mold release and its application technique shall be specified in the fabrication log sheets.

5.1.13 Oven or Autoclave Certification - Before production of parts in a specific curing facility, flat panels shall be laminated for each of the laminate types to be produced. The panels shall be of a size to provide for the required specimens in accordance with the specified test methods. Major changes in the curing facility that affect heat-up rate, vacuum, and venting shall require repetition of the preproduction testing.

Separate panels shall be included for each manufacturer's pre-impregnated material, if two or more manufacturer's materials are used. The panels shall be made using the same procedures specified for production parts with one exception. The exception shall be that no matter what

laminate orientation is used in the part layup, the panel shall be a non-tested parallel warp layup. Test specimens shall be prepared from the test panels with the testing direction parallel to the warp direction.

a The mechanical properties of the test specimen shall meet or exceed the requirements noted on the engineering drawing when tested in accordance with the applicable test method.

b Specific gravity when specified shall meet requirements of the engineering drawing. A minimum of two specimens shall be tested.

c Resin content shall meet the requirements of 5.1.3.2. A minimum of two specimens shall be tested.

d The laminates shall meet all the applicable requirements of 5.1.1.

e Materials Engineering and Quality shall review and approve the above data prior to first article fabrication.

5.1.14 Tool Qualification and First Article Fabrication - The first part fabricated per this specification for each structural design shall be tested as specified by engineering. Review of the test and inspection data generated for each first part shall be accomplished by Materials Engineering Manufacturing Engineering, and Quality prior to fabrication of additional parts to the particular design.

5.1.15 Process Control Specimens - Process Control specimens shall be fabricated as specified on the engineering drawing. The specified specimens will be one of two types, tag-end specimens and flat panel specimens.

a Tag-end Specimens - Tag-end specimens, as part of the production process shall be prepared and tested for compliance to the specified requirements. Tag-end specimens are defined as extensions of the production part which represents the production part as closely as possible in thickness, fabric orientation, number of plies, and critical processing parameters, such as local cure pressure and bleeder configuration. The drawing shall specify all above details and required tests, number of specimens, specimen configuration, and acceptable test values.

b Cure temperature is based on actual part temperature and not oven air temperature. To ensure proper cure, at least one thermocouple shall be placed in the center of outside tool surface. Heat-up rate shall be based on the leading thermocouple. Time at temperature shall be based on the lagging thermocouple.

c Preparation Prior to Post Cure - The parts shall be cleaned of all mold release and visually inspected for compliance of 5.1.1 and tested for tackiness (5.1.3.1). Acceptable parts shall be restrained on post cure tools as specified in the Detail Process Plan (5.1.10).

5.2 Fabrication of Conical Shell Structures

5.2.1 Tooling and Preparation:

5.2.1.1 GY70/934 Tape Preparation - Remove impregnated unidirectional tape GY70/934 (HY-E-1534, Fiberite Corp) from the refrigerator and permit to stabilize at room temperature. Do not remove the material from the vapor proof bag until condensation ceases on the outer surface of the bag (approximately 30 minutes).

Note: Remove only those quantities of material and reinforcement from the refrigerator that will be used during the course of the work shift.

5.2.1.2 Mandrel Inspection - Inspect mandrel/mandrels to be used as outlined in 5.1.8. The working "mandrel" or "layup tool" shall be used interchangeably in the following sections.

5.2.1.3 Male Mandrel Preparation - The male cone mandrel is prepared prior to layup as follows:

a Wipe on 1 coat of liquid release agent (3.19, Release - All #30) with clean cheese cloth pad and air dry for 15 minutes.

b Wipe on coat of carnauba base - paste wax (Ceara Mold Release Wax) with clean cheese cloth pad using longitudinal strokes, air dry and buff to medium gloss finish with clean cheese cloth pad.

c Repeat b using circumferential application strokes.

d Repeat b except this coat is only lightly buffed to remove excess paste wax.

e Repeat step a., applying second coat of liquid release agent.

f Cover mandrel layup surface with one sheet of solid 0.0001-inch thick plastic (teflon film) and carefully tape joint with thin plastic adhesive tape to eliminate wrinkles.

5.2.1.4 Graphite Tape Cutting

Preliminary graphite tape preparation is required as follows:

a The cutting board (1/4 inch thick polyethylene sheet) is laid out with an adhesive tape (mylar) pattern similar to sketch below:

AD-A072 770 MARTIN MARIETTA AEROSPACE ORLANDO FL F/G 11/4
TEST AND EVALUATION OF GRAPHITE/EPOXY COMPOSITE STRUCTURE.(U)
JUL 79 R P HEWITT, F H KOO, R D KEYS DAAG46-79-C-0006

UNCLASSIFIED OR-15448 AMMRC-TR-79-39 NL

2 OF 2
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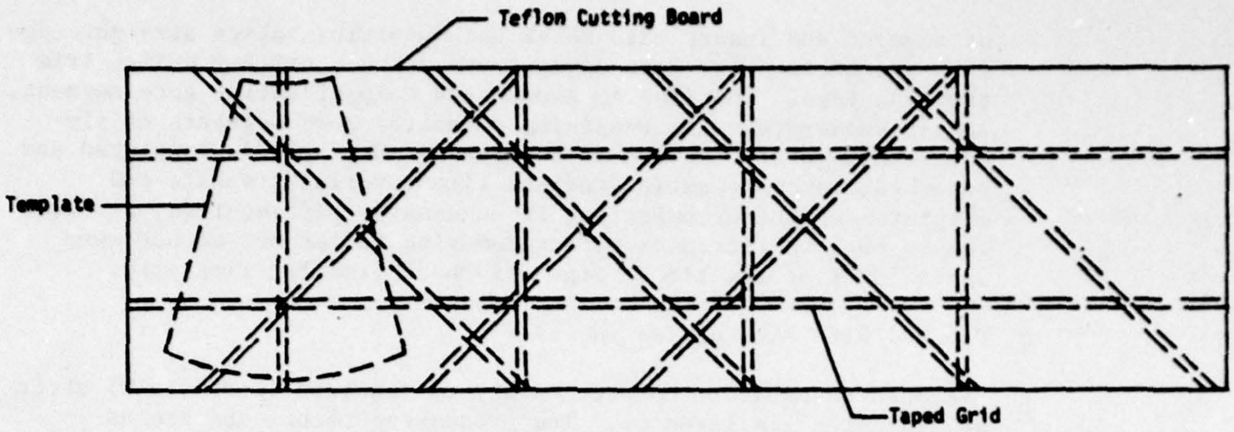


b A sheet of clear solid plastic (tedlar) is placed over cutting board and edge taped to board.

c The graphite tape is laid on the cutting board at the specified orientation and facedown to adhere to clear film (tedlar). Successive strips of graphite tape are laid immediately adjacent to previously applied strips, eliminating or minimizing gaps between strips.

d After graphite tape is placed on cutting board, cone gore segments are precut using aluminum templates and gore centerline orientation, as required. Four gore segments make one complete ply layup. A sharp utility knife is used to cut around template. The gore segments are identified, on the plastic coated paper side, with fiber orientation and stacked in groups of four (4) for each ply. After cutting, the segments are placed in sealed vaporproof bag for immediate refrigeration.

5.2.1.5 Graphite Cone Layup - Ply layup and compaction techniques are to be performed as follows:

a The gore segments required to complete the first plies are removed from refrigeration and allowed to warm to room temperature as in 5.2.1.1. A check list per 5.1.10 is prepared to assure correct ply orientation and sequence during layup.

b The first ply (4 gore segments) is placed on work bench and the plastic coated paper is carefully removed leaving the graphite tape adhering to the clear plastic (tedlar) sheet. A straight edge is positioned on the mandrel aligning it with the proper angular reference marks at top and bottom of mandrel. The gore segment is laid up with graphite against mandrel and reference edge aligned with the straight edge. Carefully smooth and compact onto mandrel with hands and/or plastic (teflon) paddle over clear plastic (tedlar) film to remove wrinkles and obtain best fit leaving segment's trailing edge available for trimming. Lift trailing edge

of segment and insert thin metal backup-strip. Align straight edge (top and bottom) for next segment and using a utility knife, trim trailing edge. Continue to smooth and compact entire gore segment. Repeat above steps for remaining three (3) gore segments of ply using butt joints between each segment. When ply is completed and smoothed, remove plastic (tedlar) film covering graphite and complete smoothing/compacting if necessary. If required, use heat gun to improve tackiness before removing tedlar but do not warm above 100°F at any time. Sign off check list for first ply.

c Proceed with each ply as in (b).

d Elevated temperature compaction may be required (per 5.1.10) after so many plys are layed up. The processing techniques are as follows:

1) Carefully cover graphite layup with one ply of solid 0.001 inch thick teflon sheet using a lap closure joint and thin plastic adhesive tape.

2) Cover with two ply of bias cut 181 glass cloth with each ply butt joined and taped together using thin plastic adhesive tape.

3) After placing an annular ring of 4 plies of 161 glass breather cloth and two (2) 4 ply patches of 482 tooling glass over vacuum ports, surround annular ring and pads with strip of sealant tape. Place rubber vacuum bag over mandrel and layup. Figure A-1 illustrates cone layup compaction setup.

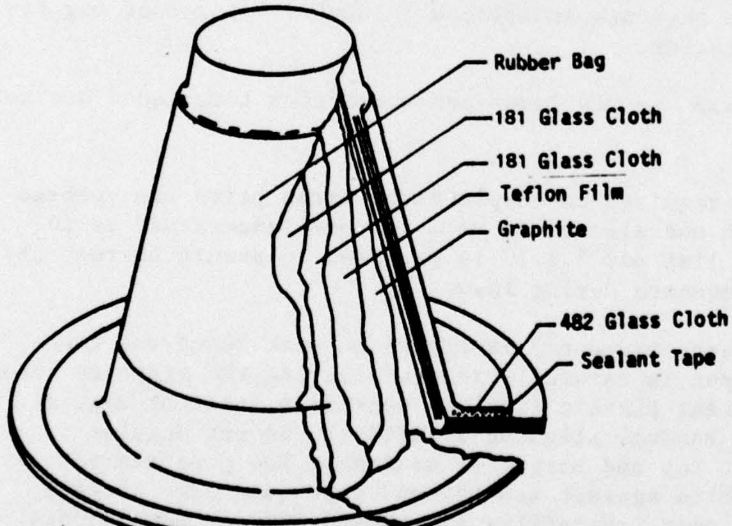


Figure A-1. Cone Layup Compaction Setup

Begin evacuation of layup and bag. After achieving a vacuum or 20 inches of mercury minimum, check layup through rubber bag for wrinkles. Eliminate wrinkles before placing setup in autoclave.

CAUTION

All layup steps interrupted prior to final cure are to be covered with vapor proof bags and placed in refrigerated (40°F) storage until work is resumed.

4) Compaction cycle is accomplished in autoclave as follows:

a Evacuate setup to 20 inches of mercury minimum.

b Heat to 150° ± 10°F (temperature controlled and monitored with two (2) thermocouples attached to mandrel wall) for 30 ± 10 minutes.

c Remove setup from autoclave and carefully smooth all wrinkles and bulges.

d Return setup to autoclave and evacuate silicone bag.

e Heat to 150°F ± 10°F and increase autoclave pressure to 50 psig and hold for 15 minutes.

f Cool setup to 80°F in approximately 30 minutes while maintaining vacuum and pressure.

g Reduce autoclave pressure to 0 psig.

h Remove vacuum bag and compaction/breather layup. Store completed compacted cone on male mandrel in refrigerator as required. Remove cone layup from male mandrel when ready for final cure in the female tool.

5.3 Cure Cycle and Finishing of Conical Shell Structure

5.3.1 Tooling and Prepartion

5.3.1.1 Female Mandrel Preparation - Prepare the female mandrel for final cure of part as follows:

a Apply first coat of liquid release agent (Release-All #30) with a clean cheesecloth pad using longitudinal strokes.

b Air dry for 15 minutes.

c Apply second coat of liquid release agent (Release-All #30) with a clean cheesecloth pad using circumferential strokes.

d Air dry for 15 minutes.

e Apply third coat of liquid release agent (Release-All #30) with a clean cheesecloth pad using longitudinal strokes.

f Air dry for 15 minutes.

g Apply fourth coat of liquid release agent (Release-All #30) with a clean cheesecloth pad using circumferential strokes.

h Air dry for 15 minutes.

i Place mandrel in oven and bake at 350 ± 10°F for 15 minutes.

j Repeat steps (a) through (f) when applying an additional three coats of liquid release agent.

5.3.2 Female Mandrel Breather/Bleeder Assembly

5.3.2.1 Using 180° gore template, bias cut two 181 glass cloth breather plies.

a Butt join and tape together each 181 glass ply with thin plastic adhesive tape.

b Place 181 glass plies over male mandrel and after carefully smoothing, temporarily tape to mandrel at top and bottom.

5.3.2.2 Using 180° gore template, bias cut one dacron cloth ply and tape butt joint with thin plastic adhesive tape.

a Slip dacron ply over mandrel and tape to previously laid up 181 cloth at top and bottom.

5.3.2.3 Cut one ply of solid 0.001 inch thick teflon sheet using 180° gore template and tape butt joint with thin plastic adhesive tape.

a Place solid teflon sheet on mandrel and tape to assembly.

5.3.2.4 With 180° gore template, bias cut one ply of 112 glass bleeder cloth and tape butt joint with thin plastic adhesive tape.

a Slip 112 bleeder cloth over mandrel and tape to assembly at top and bottom.

5.3.2.5 Using 180° gore template, cut one ply of perforated teflon sheet and tape butt joint with thin plastic adhesive tape.

a Place perforated teflon sheet over mandrel and tape to assembly at top and bottom. This completes the breather/bleeder assembly and Figure A-2 shows layup of assembly on male mandrel.

5.3.2.6 When layup and compaction of graphite cone is completed, slip over bleeder/breather assembly completed in 5.3.2 and press snugly down on assembly.

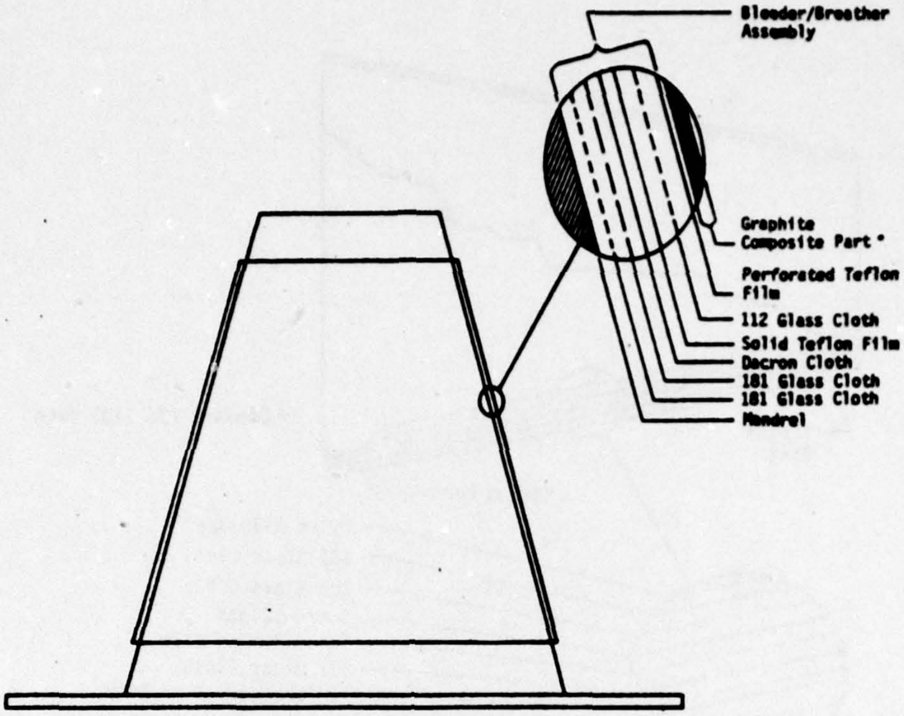


Figure A-2. Layup on Male Mandrel

a Trim excess material from both ends of bleeder/breather assembly leaving sufficient tails to allow breather access to evacuation ports when cone part and assembly are inserted into female mandrel for final cure.

After trimming, carefully remove cone and bleeder/breather assembly form male mandrel and insert into female mandrel.

b Using 1/2-inch wide mylar tape, fasten edges of breather/bleeder assembly to female mandrel at both ends.

c Make inch-wide annular breather strips from four plies of 482 glass cloth and tape to each end of breather assembly in-plane with vacuum ports. See Figure A-3 below.

d Apply ring of sealant tape (GS #213) to each end of female mandrel.

e Make nylon vacuum bag and insert into female mandrel covering graphite layup and breather/bleeder assembly. Seal nylon bag to mandrel leaving small folds in bag for expansion of bag during cure cycle.

1) Evacuate setup to minimum of 20 inches of mercury. When bag and setup seal sufficiently to obtain above vacuum, place mandrel in autoclave. Attach two thermocouples to outer wall of mandrel for temperature control and monitoring.

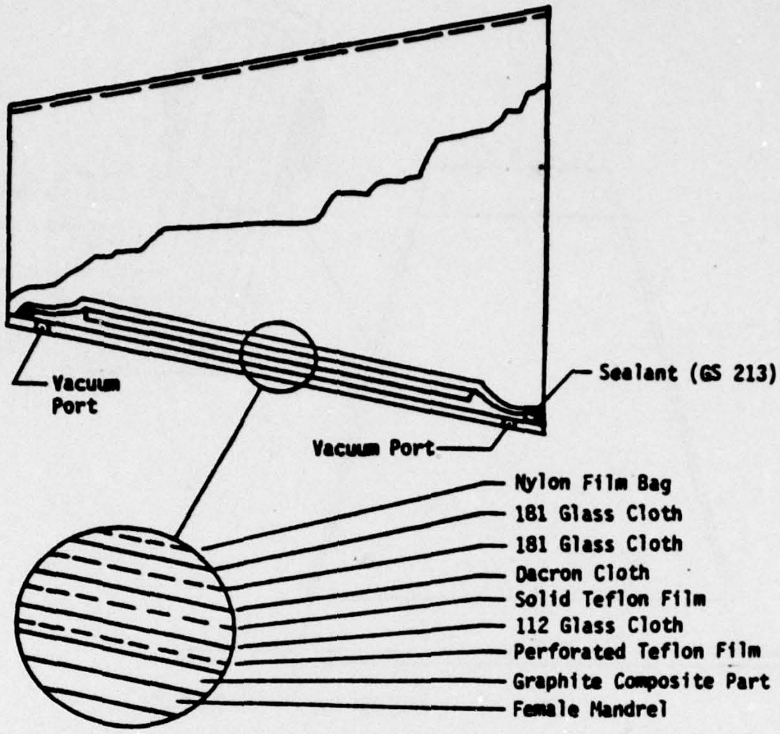


Figure A-3. Bleeder/Breather Assembly on Female Mandrel

5.3.3 Final Cure Cycle Sequence

a Install assembly in autoclave and apply vacuum. Heat to 180-200°F, open autoclave, and rub down inside surface of assembly.

b Heat to 250 ± 10°F at 3° ± 1°/minute and dwell for 15 ± 5 minutes.

c Apply 80-100 psig autoclave pressure.

d Dwell at 250 ± 10°F for 45 $^{+0}_{-5}$ minutes.

e Raise temperature to 350 $^{+0}_{-10}$ °F and dwell for 180 ± 10 minutes.

f Cool under vacuum and pressure to 100°F or less.

g Release vacuum and pressure and remove assembly.

5.3.4 Finishing Operations

a Trim parts to drawing tolerances. A high speed diamond cutoff wheel is used for trimming edges of cured laminates.

b Carbide or diamond tools are required for all drilling operations. The cutting can be done by standard steel saw blades. Edge fraying, delamination, chipping, and cracking are not acceptable and are caused by dull tools or excessive feed rates. Laminates must be backed up by solid material during machining and drilling operations.

WARNING
Use dust collection/vacuum collection equipment when machining graphite to prevent inhalation of fiber debris. Clean machining work area surfaces after completion of trimming and machining by using moistened cloths or sponges to wipe up powder fragments. DO NOT USE AIR NOZZLE TO BLOW FRAGMENTS OFF WORK SURFACES.

c Wrap finished part in plastic film (3.16) overwrapped with 1 inch foam (3.17) for protection. Part identification and tagging should be externally visible without removing protective wrap.

6.0 QUALITY REQUIREMENTS

6.1 Quality shall insure compliance with this process and perform inspection functions at the "Product Quality Verification Required" (PVQR) points as specified on the authorizing documents. Quality shall observe and verify additional inprocess operations when required.

6.2 Cross sectional examination of tag end specimens shall be conducted for all laminate sections produced under this process in accordance with 5.1.1.11. Use visual inspection aids approved by Quality Engineering. Final acceptance judgement on process visual criteria (5.1.1) shall be from a combined review effort by Project Quality Engineering and Project Materials Engineering representatives.

6.3 Process control specimens shall meet the mechanical properties as required by Engineering Drawing Callouts.

6.4 Resin content tests shall be determined by acid digestion methods per ASTM Method D3171. Minimum specimen weight shall be 10 grams.

7.0 SAFETY REQUIREMENTS

7.1 Surfaces that are cleaned by solvent wiping shall be so cleaned in a well ventilated area, and the wetted surfaces shall be kept to a minimum.

7.2 Smoking, eating, drinking and all sources of ignition are prohibited in the area while solvents are being used.

7.3 Wear protective gloves and goggles when wiping with solvents. Skin exposed to epoxies or solvents must be flushed with water followed by thoroughly washing with soap and water.

7.4 Contact lenses shall not be worn while working with any chemicals.

7.5 Chemicals shall not be poured or dumped into any sanitary drain system. Use the chemical waste for discarding these materials.

7.6 Avoid skin contact with hot surfaces during or after elevated temperature curing. Cooling parts shall be protected against accidental skin contact.

7.7 Solvents shall be used only in specified areas. Solvent-soaked cloths shall be disposed of as quickly as possible after use.

7.8 Observe dust cautions noted when machining fiber-reinforced laminates. Use adequate ventilation or vacuum pickup methods and wear protective goggles (4.10) while cutting/machining cured laminates.

8.0 Sample Fabrication Log Record Sheet (2 pages)

FABRICATION LOG RECORD SHEET
FOR LAMINATE FABRICATION

PART NO. ____________________ NEXT ASSEMBLY ____________________

PROCESS CONTROL RECORD

PERSONNEL SKILL CERTIFICATION

NAME ______________________________ DATE ______________

______________________________ ______________

______________________________ ______________

QUALITY MATERIALS VERIFICATIONS
MATERIALS BATCH NO'S: ACCEPTABLE STORAGE LIFE

____________________ ______________

____________________ ______________

____________________ ______________

____________________ ______________

MANDREL DIMENSION & SURFACE CHECK ____________________

LAYUP VERIFICATION ______________________________

COMPACTION/DEBULK RECORDINGS ____________________

STEP	TEMPERATURE	TIME	COVER PLIES	PRESSURE	QUALITY
____	____	____	____	____	____
____	____	____	____	____	____

CURE CYCLE THERMOCOUPLE LOCATION ______________

	TEMPERATURE	RATE	TIME AT TEMPERATURE	COVER PLIES	PRESSURE	QUALITY
CURE CYCLE	____	____	____	____	____	____
POST CURE CYCLE	____	____	____	____	____	____

TAG END SPECIMEN

LOCATION ______________

TRIM OFF ______________

DELIVERED TO QUALITY ______________

QUALITY ACCEPTANCE ______________

LAMINATE PACKAGED FOR STORAGE/DELIVERY

____

SPECIAL FEATURES/CONTROLS ______________________________

____

COMMENTS

APPROVALS

MANUFACTURING ______________

AREA SUPERVISOR ______________

QUALITY ______________

FABRICATION LOG RECORD SHEET
FOR LAMINATE FABRICATION

PART NO ____________________ NEXT ASSEMBLY ____________________

TOOLING MANDREL NO's. ____________________

FABRICATION EQUIPMENT REQ'D

MATERIALS	SIZE	QUALITY APPROVAL

MOLD RELEASES:
RELEASE APPLICATION SEQUENCE ____________________

LAYUP SEQUENCE & MAT'L ORIENTATION:
1st LAYUP ____________________
2nd ____________________

DEBULK/COMPACTION SEQUENCE: ____________________

MACHINING OR TRIM SEQUENCE: ____________________

TAG END SPECIMEN REQUIREMENTS: ____________________

SPECIAL FEATURES/CONTROLS: ____________________

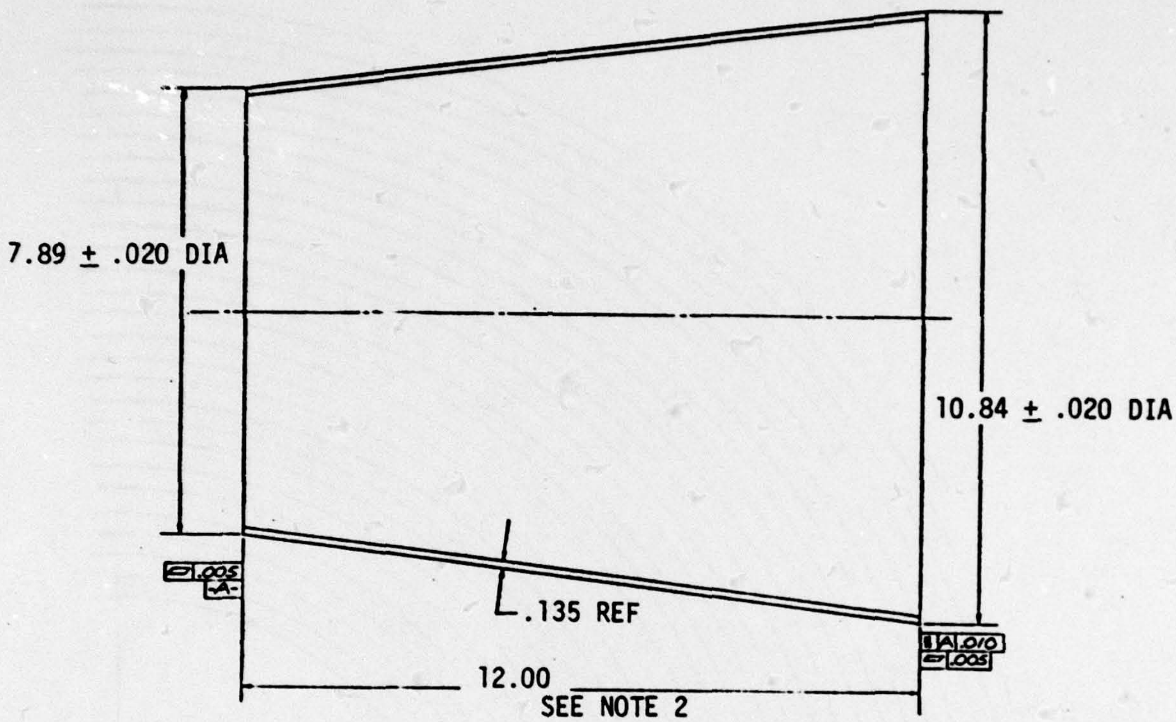
COMMENTS:

APPROVALS:

MANUFACTURING ____________________
AREA SUPERVISOR ____________________
AREA QUALITY ____________________

9.0 SAMPLE PROCESS PLAN AND PROCEDURES

9.1 Applicable Drawings - Martin Marietta Corporation, Orlando Division Drawing Number SK 27292, Reference Figure A-4



NOTES:

1. GY/70 FIBERITE 934 PLY LAMINA LAYUP (27 PLIES) $(0_2/45/90_2/-45/0_2/45/90_2/-45/0_{\underline{3}})_S$
2. THIS LENGTH WHEN FABRICATED TO BE 12.2 INCHES MINIMUM. TRIM TO B/P SIZE TO REMOVE IRREGULARITIES.

Figure A-4. Half Scale Conical Shell Specimen

9.2 Procedure

9.2.1 General - The total number of plies in this laminate shall be 27. The layup will be made in three steps. The first and second steps, ten layers each, will be followed with a compaction cycle. The third step will be the laying up of the final seven layers, a compaction cycle and followed with a final cure cycle. Each ply is comprised of four 90° gore segments. Approximately 1.5 inch excess material will be allowed for trim after final cure.

9.2.2 Gore/Ply Orientation - The following table denotes the fiber or orientation angle (flat pattern gore) and the angular position of each ply within the total layup. Figure A-5 depicts the angular position of each ply and shows a minimum of coinciding splice joints.

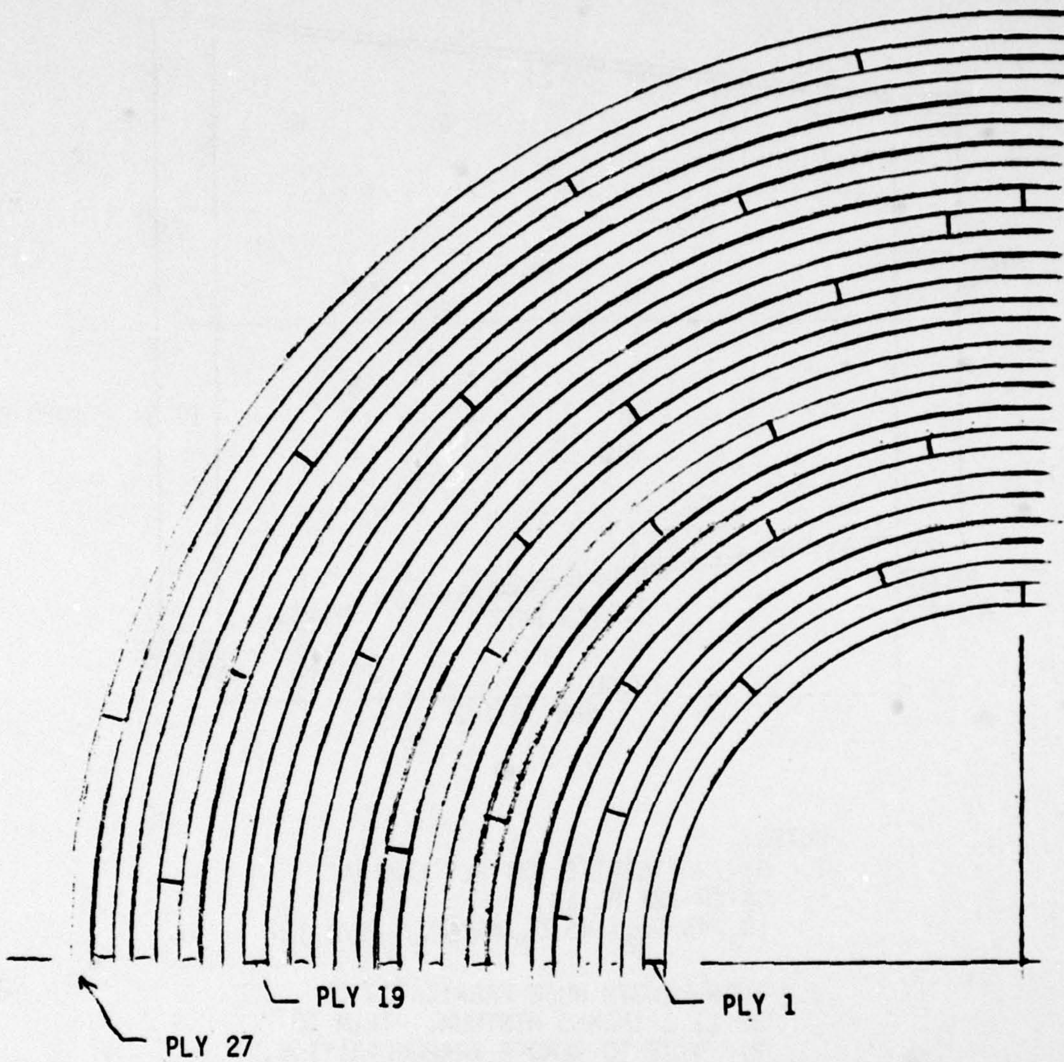


Figure A-5. Angular Positioning of Plies

PLY NO.	ORIENTATION	ANGULAR LOCATION
1	0°	0°
2	0°	45°
3	+45°	70°
4	90°	20°
5	90°	5°
6	-45°	35°

PLY NO.	ORIENTATION	ANGULAR LOCATION
7	0°	60°
8	0°	80°
9	+45°	15°
10	90°	50°
11	90°	65°
12	-45°	30°
13	0°	10°
14	0°	40°
15	0°	55°
16	-45°	75°
17	90°	25°
18	90°	85°
19	45°	0°
20	0°	45°
21	0°	70°
22	-45°	20°
23	90°	5°
24	90°	35°
25	45°	60°
26	0°	80°
27	0°	15°

9.2.3 Layup Sequence #1 (10 ply, GY70/934)

a Cut and layup first ten ply.

b Cut and position 1 ply nonperforated FEP teflon film over the layup.

c Place 2 ply of #181 glass cloth over the teflon film.

d Apply sealant tape and nylon vacuum bag. Install thermocouple under bag at edge of layup. Evacuate and check for leaks.

9.2.4 Compaction Cycle #1

a Place assembly in autoclave, apply vacuum and pressurize to 50 psig.

b Raise temperature to 150 ± 10°F at 4 ± 1°F/min.

c Dwell 15 minutes (maximum).

d Cool rapidly to 100°F or less under vacuum and pressure.

e Release vacuum and pressure, and remove bagging materials.

9.2.5 Layup Sequence #2 (10 ply, GY70/934)

a Repeat procedure 9.1.3, steps a through d, for the next 10 plies of graphite tape.

9.2.6 Compaction Cycle #2

a Repeat procedure 9.1.4, steps a through e for the second 10 ply.

9.2.7 Finaly Layup Sequence #3 (7 ply GY70/934)

a Complete layup of the GY70/934 tape.

b Cover laminate layup with 1 ply of preforated teflon film and 1 ply of #112 fiberglass bleeder cloth.

c Place 1 ply of solid teflon film over the entire layup with adequate oversize.

d Place 1 ply of dacron cloth over the solid teflon film and then 2 ply of #181 breather glass cloth over the entire layup.

e Position thermocouple in edge of layup.

f Apply sealant tape and nylon vacuum bag. Evaluate and check for leaks.

9.2.8 Final Cure Cycle Sequence (see Figure A-6)

a Install assembly in autoclave and apply vacuum.

b Heat to 250 $\pm$ 10°F at 3 $\pm$ 1°F/minute and dwell 15^{+0}_{-5} minutes.

c Apply 80-100 psig autoclave pressure.

d Dwell at 250 $\pm$ 10°F for 45^{+0}_{-5} minutes

e Raise temperature to $350^{+0°}_{-10}$ F and dwell 180 $\pm$ 10 minutes

f Cool under vacuum and pressure slowly to 100°F or less.

g Release vacuum and pressure, dissassemble and remove layup.

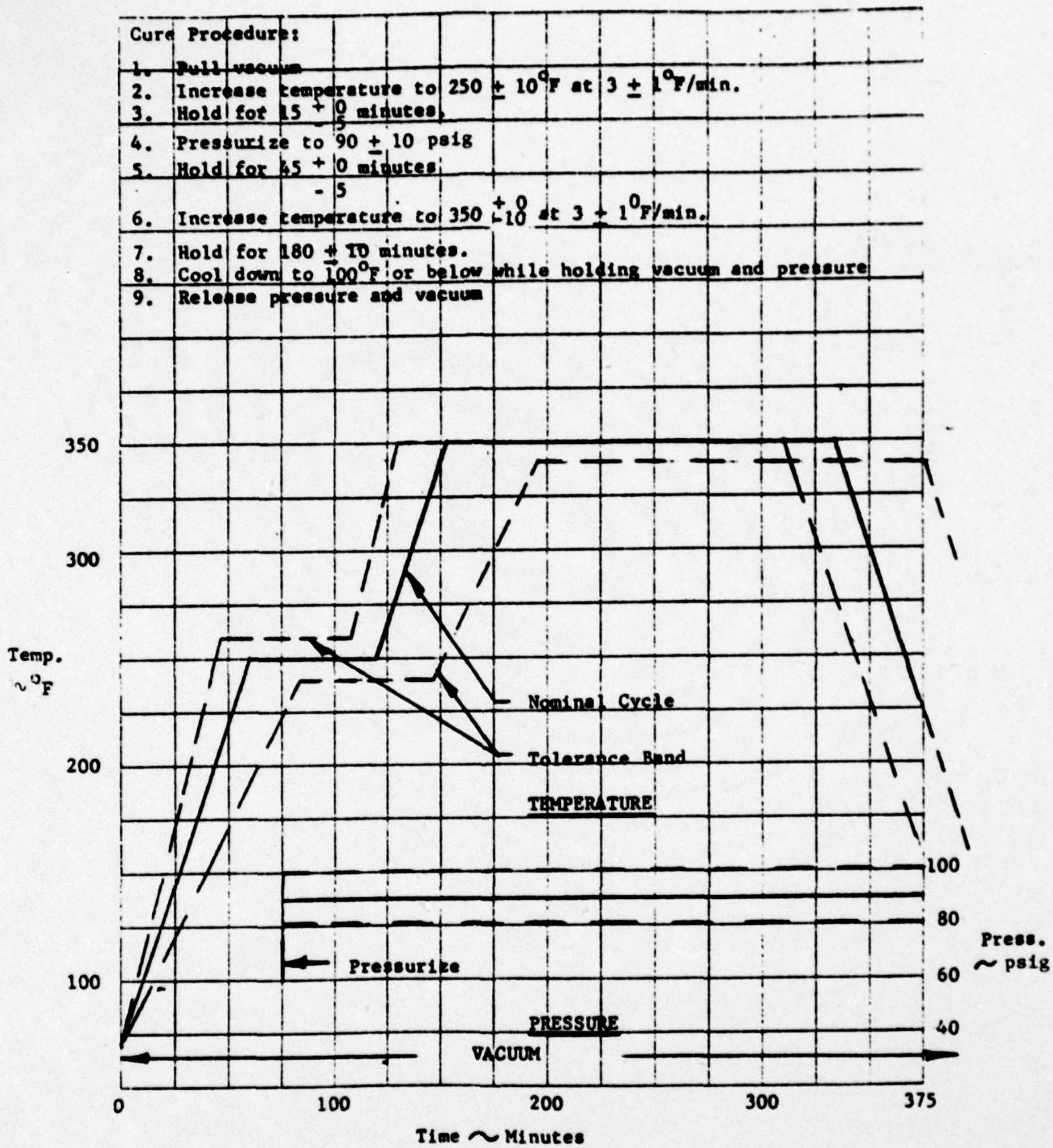


Figure A-6. Cure Cycle, GY70/934 Laminate Layup

APPENDIX B

TEST PLAN FOR COMBINED LOAD TESTS OF HALF-SCALE GRAPHITE COMPOSITE STRUCTURE

1.0 INTRODUCTION

1.1 General

This test plan is submitted to the Army Materials and Mechanics Research Center to fulfill the requirements of CDRL item A002 of contract DAAG46-79-C-0006, Test and Evaluation of Graphite/Epoxy Composite Structure. This test plan provides the necessary detailed test requirements and instructions to set up and perform combined loads testing on half scale graphite composite conical frusta.

1.2 Test Objective

The test ofjective is to provide structural data for the evaluation of the strength and stiffness properties of a half-scale ultra-high modulus (GY70/934) graphite/epoxy cone frustum under a combined loading simulating the critical in-flight design condition for a high performance BMD interceptor structure.

Evaluation of the structural properties of the conical frustum will be made by comparing the test results with analytical predictions.

The test data obtained by these tests will augment the results of axial load testing being performed at the Denver Division of Martin Marietta Aerospace.

2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The test specimens (Figure B-1) are half-scale conical frusta fabricated from ultra high modulus graphite/epoxy composite (GY70/934) prepreg tape following Martin Marietta Orlando Division drawing number SK27292 and the manufacturing process plan SPC 10720729-001. The conical frustum is 12 inches long with end diameters of 10.84 inches and 7.89 inches. The naminal shell thickness is 0.135 inches.

Inner and outer rings of 6061-T652 aluminum alloy will be bonded to this shell with Hysol adhesive EA 9309. Holes will be drilled in these rings to provide attachment to the test and loading fixtures. The aluminum rings will be sufficiently durable to be capable of refurbishment and reuse on subsequent test specimens. A total of three specimens will be tested in combined loading.

2.2 Loading Condition

The design half-scale loads are presented in Figure B-2. Superimposed upon these loads are the structural test loadings applied by the test setup. The test loads are calculated to produce duplication of the design loads at the large end of the test specimen where the critical stresses exist. Each of the three test specimens will be subjected to the identical load condition.

Notes:

1. GY70/Fiberite 934 ply lamina layup per dwg. SK27292.
2. Aluminum rings shall be flush with ends of shell.
3. Clean aluminum rings per procedure in MIL-A-9067C, para. 6.11, or equiv. and bond within 8 hours. Solvent wipe GY70 shell bonding surfaces with petroleum ether or equiv., dry, hand sand lightly, and remove dust with dry nitrogen. Bond aluminum rings to GY70 shell with EA 9309 (Hysol Div. The Dexter Corp.) per vendor's recommended mix ratio. Maintain bond line thickness of 0.004 in. to 0.125 in. cure for 72 hours at 75°F ±5°F or for 6 hours at 75°F ±5°F plus 16 hours at 120°F ±10°F.
4. GY70 shell and aluminum ring bonding surface diameters shall be concentric within 0.02 in.

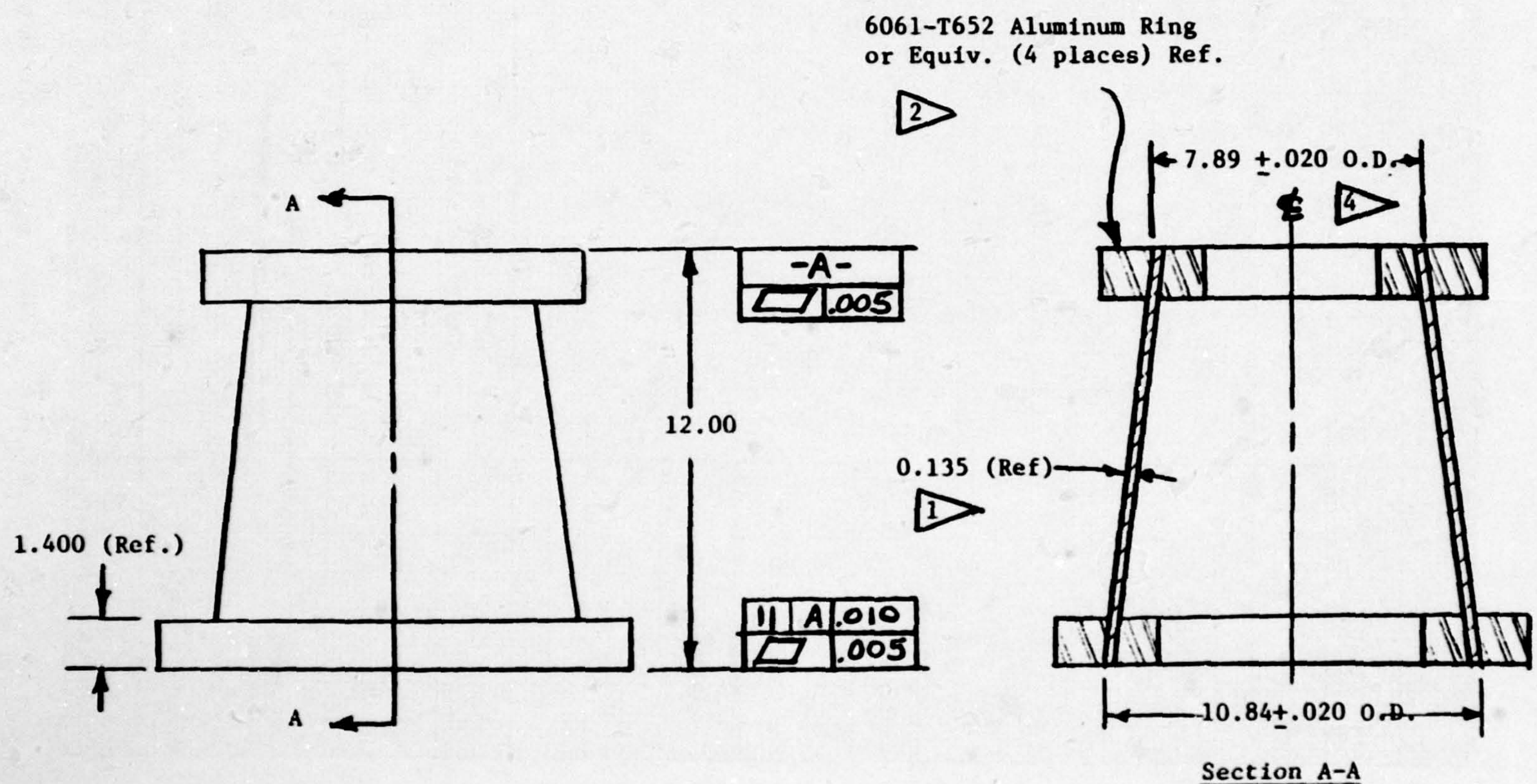


Figure B-1. Half Scale Conical Shell Test Specimen

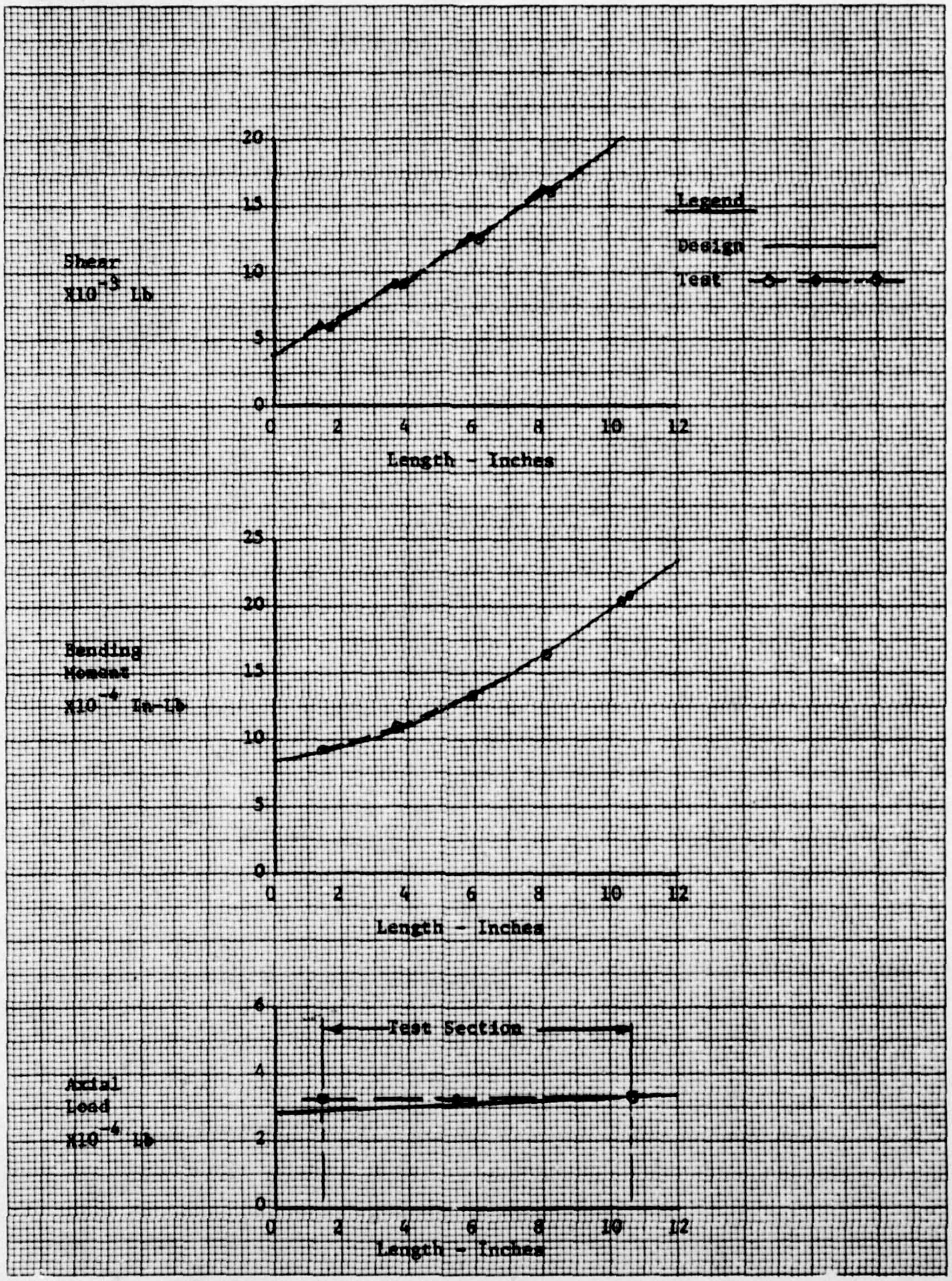


Figure B-2. Design and Test Loads (Limit)

2.3 Test Arrangement

2.3.1 Facility

The tests will be conducted in the static test area of the Mechanical Systems Laboratory of the Orlando Division of Martin Marietta Corporation.

The following equipment will be used to conduct the combined load tests:

- a 100K Hydraulic Jack (2) Messinger
- b 50K Hydraulic Jack (1) Messinger
- c 20K Hydraulic Jack (1) Messinger
- d 100K Load Cell (2) BLH
- e 50K Load Cell (1) BLH
- f 20K Load Cell (1) BLH
- g Speed-O-Max Load Cell Indicator (4)
- h Series 800 Strain Indicator (1) BLH
- i Direct Current Differential Transducers (4)
- j Hand Pump (4) Blackhawk

2.3.2 Mechanical Test Assembly

The combined load test set up is shown in Figure B-3. The conical shell test specimen will be bolted at the larger end to the test fixture with 5/16 inch diameter steel bolts (150 KS/min tensile strength) torqued to 150 in (2000 lb preload). The forward (smaller) end will be bolted to a loading fixture with 5/16 inch diameter steel bolts (150 KS/min tensile strength) torqued to 150 in-lb (2000 lb preload).

Two hydraulic jacks aligned parallel to the shell axis will provide end moment to the small end of the test specimen through a loading fixture and a third loading jack will provide a transverse shear load to the test specimen through this same loading fixture. A whiffle tree arrangement connected to loading straps wrapped around the conical shell will provide the distributed shear loading to the test specimen simulating the external pressure loading.

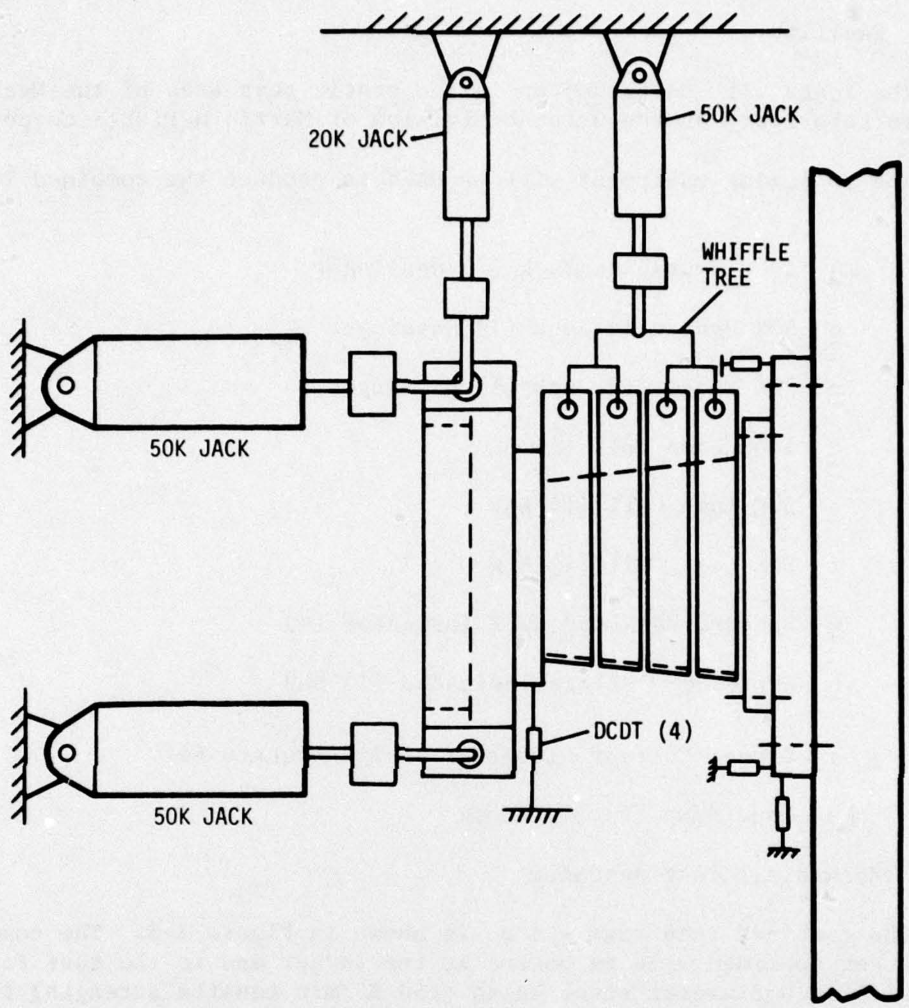


Figure B-3. Combined Load Test Setup

2.4 Instrumentation

2.4.1 Strain Measurements

A total of thirty axial type and three rosette type strain gages will be installed on the test specimen as shown in Figure B-4. Eleven gages will be installed adjacent to the fixed end where the maximum bending moment occurs. Strain gages will be placed to measure strains in the circumferential, axial, and 45° directions relative to the shell axis. Strain measurements will be taken on both the outside and inside surfaces of the shell. Eleven gages will measure strains midway between the end rings and gages will be installed adjacent to the smaller (forward) end ring.

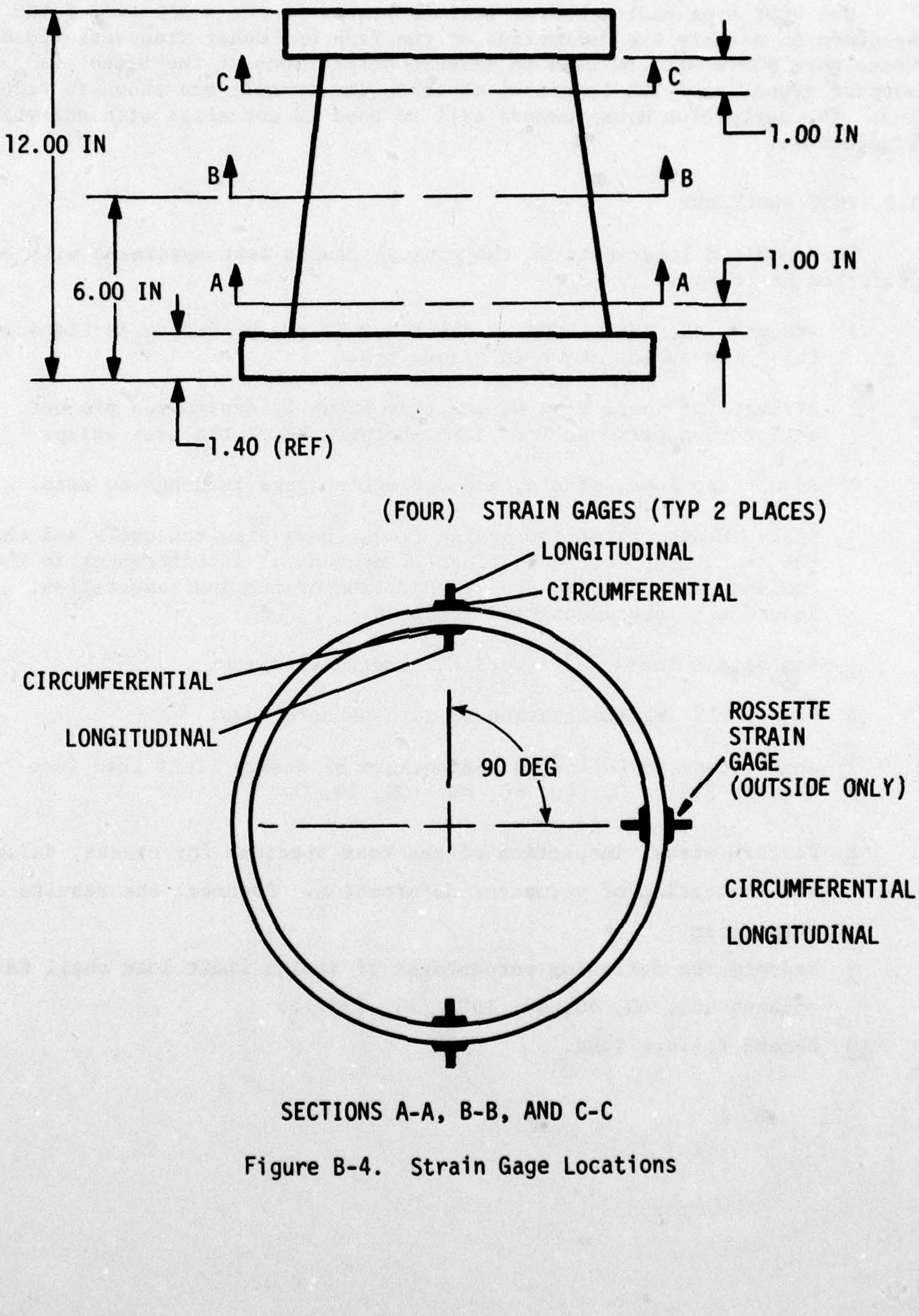


Figure B-4. Strain Gage Locations

2.4.2 Deflection Measurements

One DCDT type deflectometer will be placed at the small end of the test specimen to measure the deflection of the free end under transverse loads. Three more DCDTs will be used to measure deflections of the fixed end support structure. The locations of these instruments are shown in Figure B-3. The deflection measurements will be used to correlate with analytical predictions.

3.0 TEST PROCEDURE

The combined load tests on the conical frusta test specimens will be conducted as follows:

1 Assemble the test setup as described in the preceding sections of this plan and as shown in Figure B-3.

2 Arrange for inspection of the test setup by designated project engineering personnel and take photographs of the test setup.

3 Adjust the load, strain, and deflection gage readings to zero.

4 Apply 10 percent of the design limit loads simultaneously and check the test setup for indications of mechanical interferences in the loading apparatus and proper operation of the instrumentation. Record all instrumentation readings.

5 Remove all loads and record all instrumentation.

6 Adjust all instrumentation to zero at zero load.

7 Apply loads in following percentages of design limit load (see section 2.2): 20, 40, 60, 80, 100, 20, 0.

8 Perform visual inspection of the test specimen for cracks, delamination and indication of permanent deformation. Document the results of the inspection.

9 Reapply the following percentages of design limit load until failure occurs: 20, 40, 60, 80, 100, 120, 130....

10 Record failure load.

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